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Conceptual Modelling for Product Configuration systems

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This dissertation is submitted for the degree of Doctor of Philosophy
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ABSTRACT

Individual customization of goods and processes in different industries leads to complexity due to a growing mix of products both regarding characteristics of products and support services. In order to eliminate complexity and challenges in product/process customizing, smart IT systems called Product Configuration Systems (PCS), have been proposed as the solution both by researchers and practitioners and various benefits are mentioned from utilizing PCSs. Based on the latest literature, there are challenges reported in all phases of PCS projects including planning, development, and documentation. Moreover, the challenges become more serious when it involves complicated products/processes in engineer-to-order (ETO) companies. The purpose of this thesis is to contribute to the existing knowledge of managing PCS projects by proposing frameworks and tools to address some of the main challenges.

First, this research focuses on the reported benefits and challenges in different phases of PCS projects aligned with the gaps in the current literature. Second, the study presents a survey in order to have a comprehensive overview to assess the most important challenges in the area. Third, in order to overcome different challenges in the PCS projects, the study contributes to the literature in forms of different frameworks, tools and IT solutions. Addressing the defined challenges, the following frameworks are proposed. 1) A framework is provided for business cases in PCS projects in order to estimate the needed investments and financial return-on-investment. 2) Furthermore, the research proposes a framework and different tools to scope the whole PCS project from planning to the maintenance phase. 3) Afterwards, the study suggests a framework to manage the knowledge in PCS projects due to reported challenges. 4) In order to make it possible to model, maintain, communicate, and document complicated products/process, a framework aligned with an IT tool is developed in close collaboration with industry. 5) Finally, the study contributes to the direction of integration of PCS and other IT systems by showing the automation impact of this alignment.

The tools and frameworks developed have been evaluated based on existing literature and by empirical tests in companies. Furthermore, areas for further investigation have been identified.

DANSK RESUMÉ

Individuel kundetilpasning af produkter og processer i forskellige brancher fører til stigende kompleksitet på grund af et stadig større produkt sortiment, både hvad angår produkternes karakteristika og service-support. For at fjerne kompleksiteten og imødegå udfordringerne ved produkt/proces-kundetilpasning har både forskere og praktikere som løsning foreslået intelligente IT-systemer kaldet Produkt Konfigurering systemer (PCS). Fordele ved at benytte PCS er diskuteret i litteraturen. Den nyeste litteratur fremhæver at der er udfordringer relateret til alle faser af PCS-projekter, herunder planlægning, udvikling og dokumentation. Endvidere bliver udfordringerne større, når der er tale om komplicerede produkter/processer i ordre initierede ingeniør virksomheder (ETO). Formålet med denne afhandling er at bidrage til den eksisterende viden om ledelse af PCS-projekter ved at foreslå metoder og værktøjer, der kan hjælpe med at løse nogle af disse udfordringer.

Først, fokuserer denne afhandling på de metoder, der anvendes samt udfordringer ved de forskellige faser af PCS-projekter set i forhold til manglerne i den eksisterende litteratur. Dernæst præsenteres en spørgeskema undersøgelse, hvis formål er at give overblik over og identificere de vigtigste udfordringer, der er på området. For det tredje bidrager studiet til litteraturen i form af metoder, værktøjer og IT-løsninger med formål at afhjælpe de forskellige udfordringer, som man har ved PCS projekter. Følgende værktøjer er præsenteret: 1) En metode for udvikling af business cases i PCS- projekter til vurdering af de nødvendige investeringer og økonomiske investeringsafkast. 2) Derudover foreslår afhandlingen en metode og forskellige værktøjer til vurdering af projekt afgrænsning af hele PCS- projektet fra planlægningsfasen til vedligeholdelsesfasen. 3) Dernæst foreslår studiet en metode for viden-styring i PCS projekter på baggrund af kendte udfordringer. 4) For at kunne modellere, vedligeholde, kommunikere og dokumentere komplicerede produkter / processer er der i tæt samarbejde med erhvervslivet udviklet en metode til at dokumentere modellerne, der er implementeret i et IT-værktøj. 5) Endelig bidrager studiet til at give retningslinjer for integrering af PCS og andre IT-systemer ved at vise automatiseringseffekten af denne tilpasning.

De metoder, værktøjer og IT-løsninger, der er udviklet til at styre PCS projekter er evalueret i forhold til eksisterende litteratur og ved empiriske test i virksomheder. Desuden er der identificeret områder til yderligere undersøgelse.

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I would like to thank my family for all their love and encouragement. For my parents who raised me with a love of science and supported me in all my pursuits. For my sisters, Mitra and Saeedeh, and my stepbrother Afshin who were always the sources of inspiration.

Lastly, my deepest thanks goes to my best friend, soul-mate, and husband. I married the best person out there for me six years ago. There are no words to convey how much I love him. Alireza has been a true and great supporter and has unconditionally loved me during my good and bad times. I truly thank you for sticking by my side, even when I was irritable and depressed. I feel that what we both learned a lot about life and strengthened our commitment and determination to each other and to live life to the fullest. Thank you.

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LIST OF ABBREVIATIONS AND ACRONYMS

BOM	Bill of material
BC	Business case
CAD	Computer Aided Design
CRC Card	Class, Responsibilities and Collaboration Cards
DRM	Design research methodology
ERP	Enterprise resource planning
ETO	Engineer-to-order
IT	Information Technology
KM	Knowledge Management
MC	Mass Customization
PCS	Product Configuration System
PVM	Product Variant Master
ROI	Return On Investment
RUP	Rational Unified Process
RQ	Research Question
UML	Unified Modelling Language

1 INTRODUCTION

In order to deal with the challenges from Mass Customization (MC), literature is concerned with different implementation methods of MC (Blecker et al., 2004). Other researchers suggest to facilitate modelling methods and dedicated IT systems to increase the effectiveness and efficiency of the specification process (Hvam et al., 2006; Salvador and Forza, 2004). With the advancement of information technology (IT) systems, the trend for diversification is reinforced by the ability to customize individual aspects on products in a more efficient manner and thus became an important aspect for today's competitive market (Pine, 1993). Product Configuration Systems (PCS) are attracting attentions to support the tasks involved in the customer-oriented customized processes related to the specification of products (Hvam et al., 2008). There are, however, challenges reported regarding planning, developing, and maintaining PCSs. This PhD thesis focuses on challenges in different phases in PCS projects and proposes frameworks and IT solutions to overcome some of the main challenges in different phases of PCS projects.

The remainder of this chapter is as following. In section 1.1 and1.2 the concept of product customization and the significance of the support of IT systems for product customization in industry are elaborated. Moreover, the reasons for solving the mentioned challenges concerned with product customization with use of PCS are supported with the evidence from current literature. In section 1.3, the gap in the literature is highlighted regarding the main challenges in different phases of PCS projects that highlight the need for more standardized the frameworks for PCS projects. The aims and scope of the PhD research is explained in section 1.4 while section 1.5 illustrates the expected structure of the following report.

1.1 Product customization

Product customization or personalization has recently replaced the mass production market (Kotler, 1989). Customization of products is the concept of configuring products by selecting feasible combinations from predefined compositions connected with rules

(ElMaraghy et al., 2013). The demand toward higher product variety and customization has been increasing even further in recent years. Industries try to compete by providing more options for their customers in order to establish stronger economic benefits (Piller, 2004). On the other hand, customers value establishing their unique products based on their own preference (Schreier and Prügl, 2011). Apart from offering a wide product variety, to react in minimum time to deliver the requirements is of great importance (Salvador and Forza, 2004). The quality of the deliverable product should not be under the influence of time or variant choice in the product even for complicated products (Trentin et al., 2012a).

1.2 Challenges of product customization

The increase in variety and it is particularly evident on the example of engineer-to-order (ETO) companies leads to an increase in complexity range and product variety. ETO companies core business is to create highly engineered complex product variants that are engineered to the specific requirements of a customer (Wikner and Rudberg, 2005). ETO variants are generally reflecting a particular highly individual customer requirement. Managing variety throughout the entire products supply chain is one of the major challenges in customizing the products. Grouping of similar variants into families is a fundamental enabler of designing, planning and producing variants efficiently (ElMaraghy et a. 2013). Product families contain variants of the products and their parts, components and configurations (ElMaraghy 2009; ElMaraghy 2007) in order to better meet the diverse needs of today’s highly competitive global marketplace, increase variety, shorten lead-times, and reduce costs (Kumar et al., 2009). One of the highly recommended solutions is PCS as expert systems that support product customization by describing how predefined entities (physical or non-physical) and their properties (fixed or variable) can be combined (Hvam et al., 2008). The next section introduces PCS as an IT smart solution to solve the challenges in product customization in ETO companies.

1.2.1 Product configuration: a smart IT solution

PCS can be applied to support the decision-making processes in the sales and engineering phases of a product, where the most important decisions regarding product features and product costs are made (Hvam et al., 2008). PCS enable companies to develop product alternatives to facilitate the sales and production processes (Felfernig, Hotz, et al., 2014) by incorporating information about product features, product structure, production processes, costs and prices (Forza and Salvador, 2007a). This information is modelled in PCS during their implementation (Forza and Salvador, 2007a). Automation of engineering processes is increasingly prevalent in multiple lifecycle phases such as design, manufacturing and service support (Verhagen et al., 2015). The PCS receives the individual customer requirements, configures the product based on the defined solution space, performs the calculations and finally generates all the necessary outputs including: proposals, bills of material, price calculation sheets or even CAD drawings (see Figure 1-1). Widely used in various industries, PCS can bring substantial benefits, such as shorter lead times for generating quotations, fewer errors, increased ability to meet customers’ requirements regarding product functionality, the use of fewer resources, optimised product designs, less routine work and improved on-time delivery (Ardissono et al. 2003; Barker et al. 1989; Hvam et al. 2006; Petersen 2007; Forza & Salvador 2006).

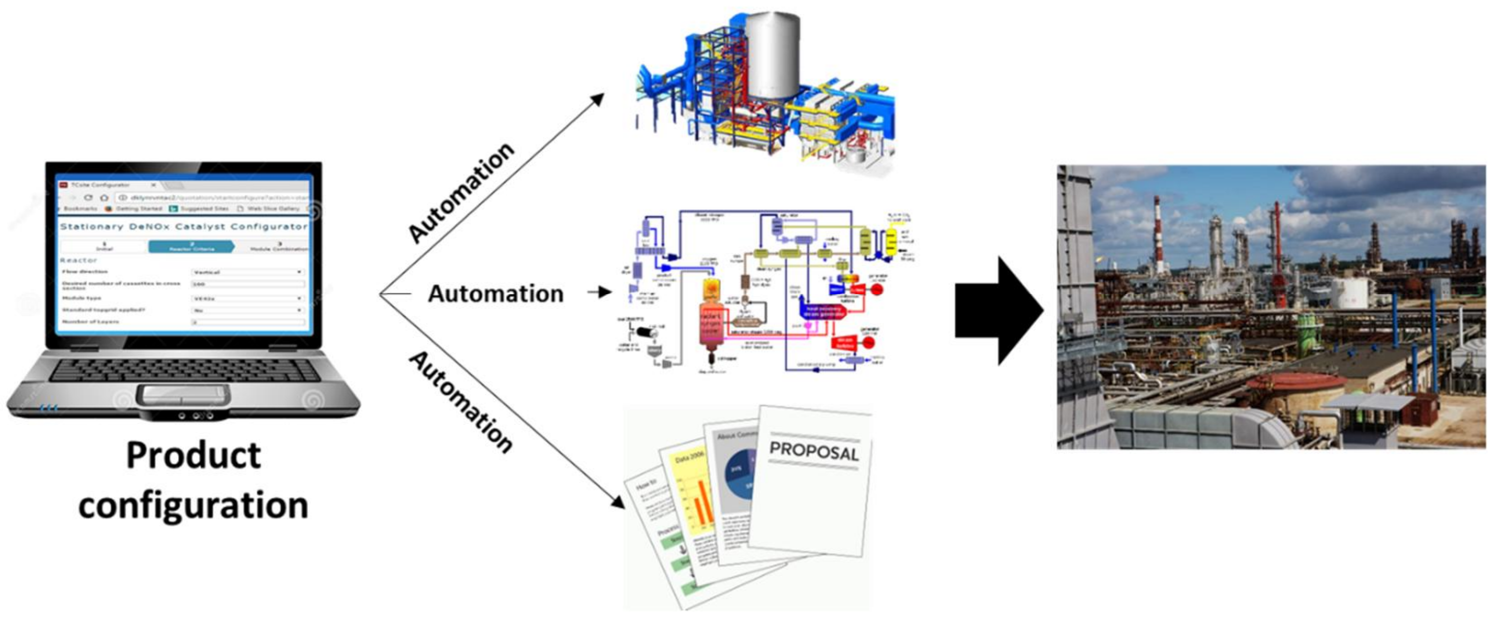


Figure 1-1 PCS and automation of the sales and engineering process

The key points to successfully deploy configuration technologies are: 1) Avoiding erroneous and suboptimal offers, 2) Avoiding MC, 3) Complexity handling of needs elicitation, 4) Knowledge integration, and 5) Efficient knowledge management (Felfernig, Hotz, et al., 2014). In Table 1-1, the main challenges companies implementing a mass customization strategies face are listed along with how PCSs can help companies to solve those challenges (Felfernig, Hotz, et al., 2014).

Table 1-1 Product customization challenges and the realized benefits from using product configuration technology (Felfernig, Hotz, et al., 2014).

MC challenges in ETO companies	How PCSs can address the challenges of MC
1) Avoiding Erroneous and Suboptimal Offers (Heiskala et al. 2009; Barker et al. 1989; Haug et al. 2011)	Prevent fire-fighting in manufacturing from errors in the sales specification, shorter lead times needed for specifications, increased sale, lower personnel cost, stable effort estimation, improved and more uniform quality, stable schedules, less customer complaints, less complexity in the sales process, reduction in product model obsolescence, save customer time in specification
2) Mass Confusion (Heiskala et al. 2009 (Huffman & Kahn 1998; Juha Tiihonen et al. 1996; Von Hippel 2001; Felfernig et al. 2006)	Customer participation in design, Corporate memory, Finding right amount of offered customization
3) Complexity Handling of Needs Elicitation (Heiskala et al. 2009; Ardissono et al. 2003; Tiihonen et al. 1998a; Tiihonen & Felfernig 2010; Falkner et al. 2011)	Increased sales, Preference knowledge, Open innovation, Reduction in inventions, Component sharing across product lines
4) Knowledge Integration (Liliana	Reliable demand prediction, Decreased

Ardissono et al. 2003; Juha Tiihonen et al. 1996; Tiihonen et al. 1998a)	time to market, Less errors
5) Efficient Knowledge Management (Mittal & Frayman 1989; Heiskala et al. 2009; Heiskala et al. 2009; Felfernig et al. 2006)	Efficient development, Efficient maintenance, Extent of organizational and cultural changes, Long term management of delivered product individuals, reconfiguration, Configuration knowledge changes frequently

Challenge 1: Avoiding Erroneous and suboptimal offers. Offering highly variant products requires sales need time to understand the product structure. The result of being confronted with high variability are errors that are often not noticed before production (Heiskala et al., 2007). Configuration technologies can tackle this challenge by constraint technologies that support automated feasibility checks of customer requirements which leads to shorter lead time, increased sales, less resources, and stable schedule.

Challenge 2: Avoiding Mass Confusion. Large and complex product structure lead to mass confusion (Huffman and Kahn, 1998) which makes the customer confused by the selection and finally unable to make a decision. PCSs can provide a search interface that helps to narrow down the number of relevant options. Personalization technologies support more efficient decision processes (Felfernig et al., 2006).

Challenge 3: Complexity Handling of Needs Elicitation. It is difficult to identify the relevant configuration without a clear view of the users' preferences (Falkner, Felfernig, et al., 2011). User interfaces in PCSs support customers in finding the right configuration which leads to increase in sale and deep understanding of market requirements.

Challenge 4: Knowledge Integration. Businesses are strengthening the communication and knowledge sharing with customers. PCSs can be integrated into a larger system to decrease the time to market, reduce order and processing errors, and increase profitability.

Challenge 5: Efficient Knowledge Management. The products knowledge may exist in a variety of sources including product data management systems, spreadsheets, legacy enterprise and CRM systems, or even in the heads of soon-to-retire employees (Felfernig et al. 2014). PCS centralize and manage all the knowledge.

1.3Problem statement

Over the previous years, PCS project applications in different kinds of industries is investigated through surveys and case studies research. The outcomes reveal benefits regarding saved man hours, costs and etc. in different companies (Ardissono et al. 2003; Barker et al. 1989; Hvam et al. 2006; Petersen 2007; Forza & Salvador 2006). Furthermore, the results demonstrate the reported challenges during the planning, development and maintenance; which leads in reducing the performance and efficiency or even make the project to be a failure. However, the challenges related to utilizing PCSs in companies have not been addressed in the literature to the same extent as the benefits, as there is a tendency to highlight the success of the implementations (Haug et al. 2012). However, the challenges should get more attention both from practitioners and the research community as there is a need for the most efficient frameworks to address some of the main challenges in PCS projects.

The current literature demonstrates the reported challenges during the planning, development and maintenance phases of PCS projects; which result in reducing the performance and efficiency of the PCS projects or even makes the project to be a failure.

1.3.1 Challenges of product configuration projects

There are challenges reported in different studies regarding planning, developing, implementing and maintaining PCS projects. In Table 1-2, the challenges are grouped based on literature and experiences working with PCS projects. Each of the group is related to different phase of PCS projects. The different phases of PCS determined as: Planning, Development, Implementation, and Maintenance (Figure 1-2) (Booch et al., 1999) (Hvam et al., 2008).

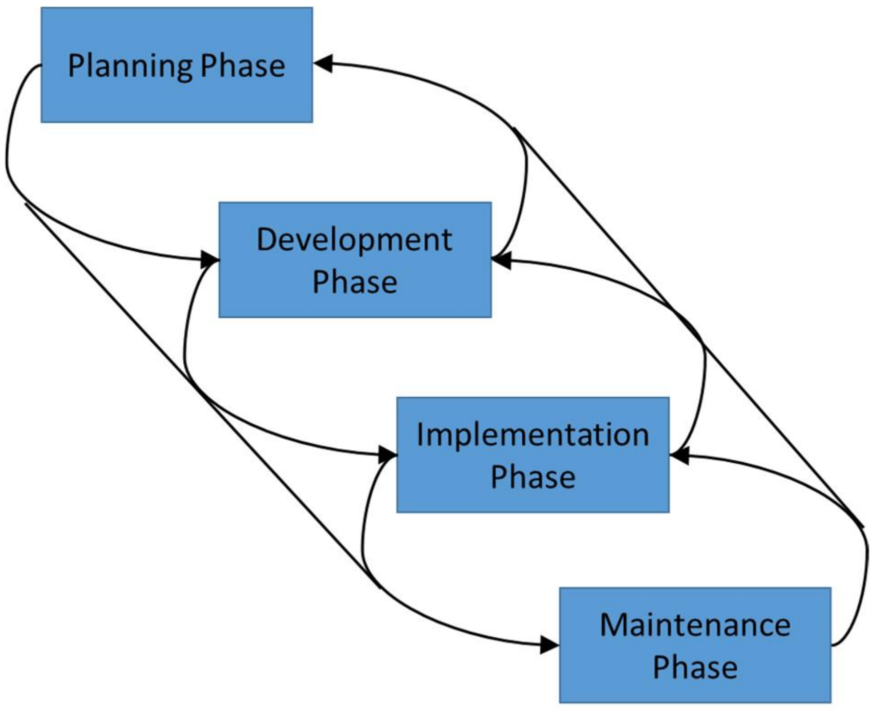


Figure 1-2 The object-oriented project life cycle, adjusted from (Booch et al., 1999)

Barker et al. (1989) presented the challenges as cross-functional business needs, as the implementation of the PCS enhances changes in the business processes that require support from top management. Tiihonen et al. (1996) concluded that inadequate tools and methods for modelling account for the main challenges of managing the PCS models. Tiihonen et al. (1998a) described the main challenges in terms of managing the knowledge in long-term PCS projects to ensure it is kept up to date, which requires tools to match the knowledge embedded in the PCS of the companies' products and processes. Ariano and Dagnino's (1996) performed a study where the main challenges were described in terms of the few numbers of employees who understood the system. This situation caused difficulties when the only employee that had a full understanding of the system left the company soon after the development. Blecker et al. (2004) described that PCSs do not support the front-end sufficiently and emphasized the need for PCSs to support customers in the configuration processes and to find an optimal solution that fulfils the requirements.

Felfernig et al. (2000) explained that the complexity in the software development of PCSs requires highly technical knowledge from experts and the knowledge base has to be adapted continuously because of the changing components and configuration constraints. However, the development and the maintenance time for PCSs is short and strict. Aldanondo et al. (2000) explained the challenges regarding the two different kinds of required knowledge to develop the PCS: industrial expertise and configuration expertise. Forza and Salvador (2002) explained the main challenges of implementing a PCS in a small manufacturing company in terms of product modelling. In another study, Forza and Salvador (2002) described the main challenges of implementing a PCS in terms of personal role changes, inter-function collaboration and software personalization. Forza et al. (2006) described that for highly complex products consisting of a very large solution space, it may not be economically feasible to implement a PCS. Ardissono et al. (2003) identified the main challenges experienced with PCSs in terms of increased complexity of products and services offered, which results in increased complexity of the systems, making it difficult for the end-user to use PCS due to a lack of technical knowledge. Heiskala et al. (2005) identified the challenges related to PCSs with a focus on services. Based on the literature, they described challenges which are confirmed/disconfirmed in relation to services based on two case studies. Heiskala et al. (2007) described the challenges relating to the introduction and long-term management of PCS based on the previous literature addressing PCSs. Hvam et al. (2006) described the challenges in terms of knowledge acquisition and product modelling for complex products in PCS and communication difficulties between domain and configuration experts. In another study, Haug and Hvam (2007) expressed that documentation of PCSs is often not maintained after the PCS becomes operational as the documentation process is too time-consuming. Petersen (2007) found the main challenges of implementing a PCS in engineering companies to be the product characteristics, customer relations and long-term projects. Table 1-2 summarizes all the related literature to challenges while planning, developing, implementing and maintaining PCS projects. This table reveals the nature of different challenges to separate the technical issues and management challenges.

Table 1-2 The categories of the challenges reported for PCS projects

Related Phases of PCS projects	Challenges in relation with management of PCS	Nature of challenge	Main contributions
Planning	Resource constraints	Lack of personnel for modelling the PCS and for gathering and providing information.	(Aldanondo et al. 2000; Ariano & Dagnino 1996; Barker et al. 1989; Forza & Salvador 2002b; Haug et al. 2012; Heiskala et al. 2005; Heiskala et al. 2007)
Planning	Product-related challenges	Challenges in the product assortment that are commonly described in complexity of the product structure.	(Petersen 2007a; Aldanondo et al. 2000; Barker et al. 1989; Forza & Salvador 2002b; Forza & Salvador 2002a; Forza et al. 2006; Heiskala et al. 2005; Heiskala et al. 2007)

Development	IT (technical) challenges	All technical challenges related to IT systems (e.g. integration, UIs).	(Tiihonen et al. 1998b; Ardissono et al. 2003; Barker et al. 1989; Blecker et al. 2004; Felfernig et al. 2000; Cipriano Forza & Salvador 2002; Heiskala et al. 2007; Tiihonen et al. 1996; Tiihonen et al. 1998a)
Development, maintenance	Knowledge acquisition challenges	The process of gathering knowledge in the development and maintenance phases, and the availability of information.	(Aldanondo et al. 2000; Ardissono et al. 2003; Felfernig et al. 2000; Haug & Hvam 2007; Heiskala et al. 2005; Heiskala et al. 2007; Hvam et al. 2006; Tiihonen et al. 1996; Tiihonen et al. 1998b)
Development, maintenance	Product modelling (knowledge representation) challenges	Challenges related to structuring the product model and reflecting the knowledge to be embedded in the PCS.	(Aldanondo et al. 2000; Ardissono et al. 2003; Felfernig et al. 2000; C. Forza & Salvador 2002; Cipriano Forza & Salvador 2002; Haug & Hvam 2007; Heiskala et al. 2007; Hvam et al. 2006; Tiihonen et al. 1996; Tiihonen et al. 1998)
Implementation	Organizational challenges	Lack of support from management and resistance to change.	(Ariano and Dagnino, 1996; Barker et al., 1989; Forza and Salvador, 2002b; Haug et al., 2012a; Heiskala et al., 2007; Hvam et al., 2006; Tiihonen, Soininen, et al., 1998)

Based on the literature, it can be concluded that there are numerous challenges in the different phases of the PCS projects. This highlights the need for frameworks, in order to simplify the process of PCS projects. This research suggests frameworks to enable ETO companies and practitioners to increase the benefits from using PCS.

1.4 Aim and scope of the research

The focus of this PhD thesis is to solve some of the main challenges in the different phases of PCS projects. PCS projects are divided to 4 different phases listed as: Planning, Development, Implementation, and Documentation (Booch et al., 1999; Hvam et al., 2008). There are challenges related to different phases of PCS projects reported in the current literature (section 1.3). While, the literature provides tools, methods and framework, there are still under solved challenges reported from both academia and industry. By addressing these challenges in PCS projects, man-hours, lead times and cost can be decreased during the project planning, development as well as after the implementation in maintenance phase and further developments.

Based on literature and due to the complexity of PCS projects, there are requirements for standard ways of managing PCS projects align with the tools and techniques to overcome projects challenges. By addressing the issues and challenges related to planning, development and maintenance of PCS, solutions including tools, frameworks and methods can be developed to improve the current situation.

Research Objective:
To frame and improve the management process of PCS projects: planning, development, and maintenance phases

In order to provide an answer, the research objective of this thesis is divided into five research questions (RQs) and will be elaborated in Section 2. The main aspects of PCS projects are the following:

- Structured business cases before planning the project, motivations, benefits and challenges in PCS management,
- Scoping PCS and having a structured planning phase,
- Managing knowledge in PCS,
- Modelling, documentation and maintenance of the PCS projects,
- PCS integration with other IT systems

1.5 Structure of the thesis

In Figure 1-3 the structure of the thesis is illustrated. The same colour-coding is used throughout the report in order to connect the relevant topics and RQs.

The Introduction chapter provides an overview of the thesis - why we need this research project and what are the goals regarding the mentioned challenges. Based on literature, this chapter provides a summarized overview on product customization and the challenges, industries face regarding product specifications. Then, the solution for these challenges is suggested as the IT smart systems, which can limit the solution space and automatically manage the specification process. First, relevant studies are presented demonstrating how PCS can solve the reported challenges of product customization. Next, the problem statement describes the challenges available in the whole life cycle of PCS projects from planning to development, and maintenance. The PhD thesis contribution is concerned to propose new solutions and framework to address the reported challenges of PCS projects.

Chapter 2 explains the research design, introduces the participants and the procedures used in the research design. Furthermore, the chapter explain the research objectives and research questions and different stages of the research which is the structure of the thesis.

This is followed by the literature review in Chapter 3, which is split across eight main sub sections. The first part consists of a review of differences and similarities of PCs and IT projects. The second and third section includes the review of the available literature on PCS development strategies and reported benefits which lead to have a formalized Business Case (BC) for PCS projects in section 3.4. This section is followed by another section which is the next phase of PCS projects and describes the literature available for scoping PCS projects. The section 3.6 of Chapter 2 provides an overview of Knowledge

Management (KM) in for IT systems is provided. Section 3.7 discusses and elaborates the available modelling and documentation techniques for PCS projects. Finally, the last section of this chapter includes a review of studies about the integration of PCs projects with other IT systems across the supply chain.

Chapter 4 gives a broad outline of the procedures used for the data analysis in eleven articles included in this thesis. This chapter emphasizes and answers the RQs provided in Chapter 2 elaborately. Each of the main articles are summarized and discussed.

Chapter 5 concludes and discusses the thesis by summarizing the results, discussing the theoretical contributions of the study, revisiting the research hypotheses, suggesting pedagogical implications, noting the limitations, and suggesting potential avenues for further research.

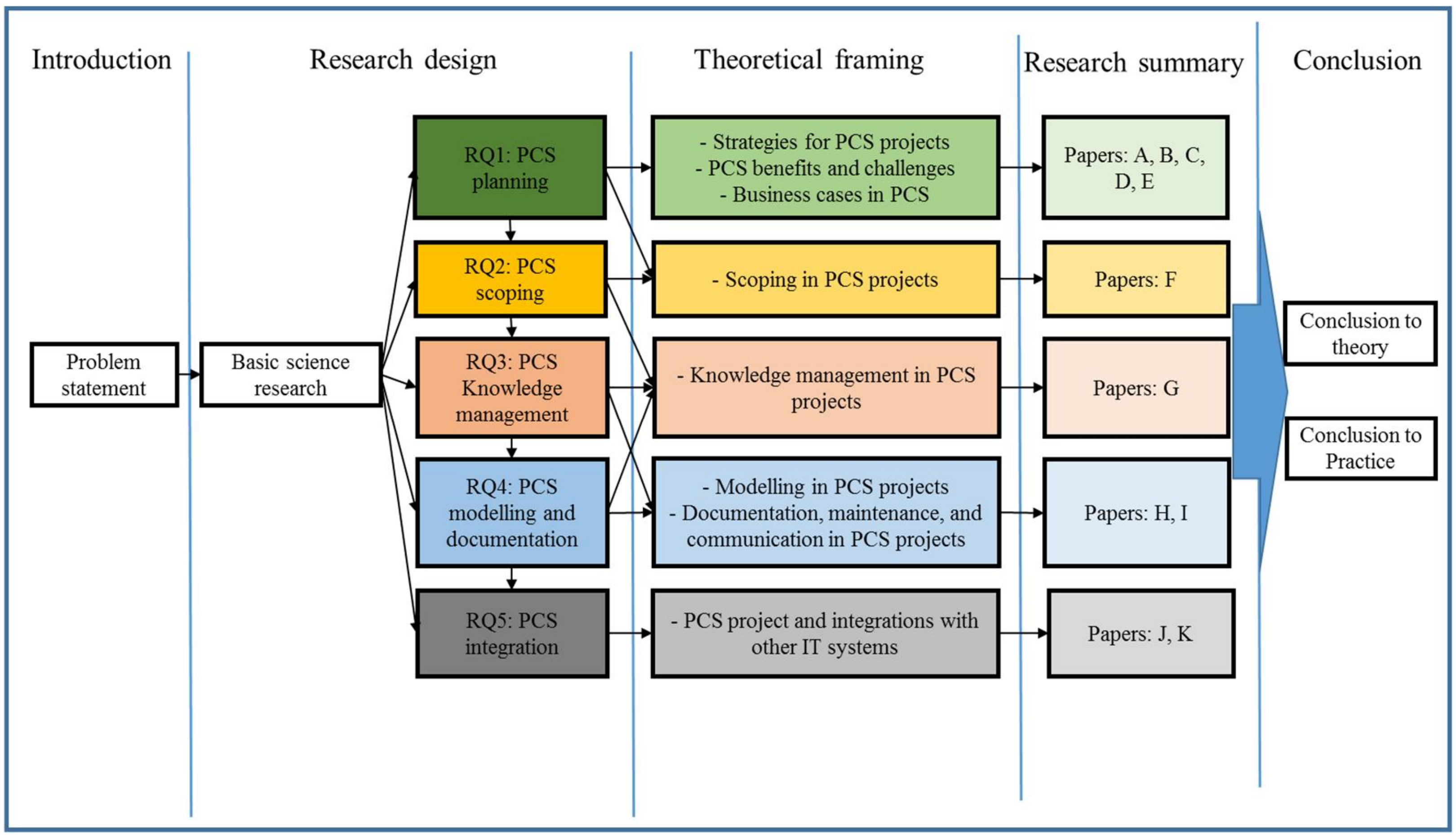


Figure 1-3 Structure of the thesis

2 RESEARCH DESIGN

2.1 Research objectives and research questions

As discussed in the previous section, the market is moving towards the customized products and customers tend to order personalized products. The results of the product customization are complexity in product families, confusion in processes, knowledge management challenges and need for integrations and alignments across different sections of the companies. One of the verified solutions is a smart IT tool to take over the manual work and include all the product families' knowledge in order to configure the products. The capabilities required for developing and implementing PCS needs to be investigated in order to address the challenges reported in Section 1.3 listed in Table 1-2. The overall research objective of this research can be broadly formulated as below:

Research Objective: To frame and improve the management process of PCS projects: planning, development, and maintenance phases

This research objective is very broad and gives the opportunity to formulate potential RQs across the PCS projects phases. The management of PCS projects within a company can be performed taking into account the four different phases as shown in Figure 1-2, while in this PhD project, we considered and focus only on three phases. The implementation phase which has a focus on organizational changes at the company while developing PCS projects is skipped in this research. The reason is to be deeply concentrated on other three phases during the limited time during PhD. In order to provide concrete answers to the mentioned challenges, the research objective is divided into RQs, which are elaborated below (see Figure 2-1).

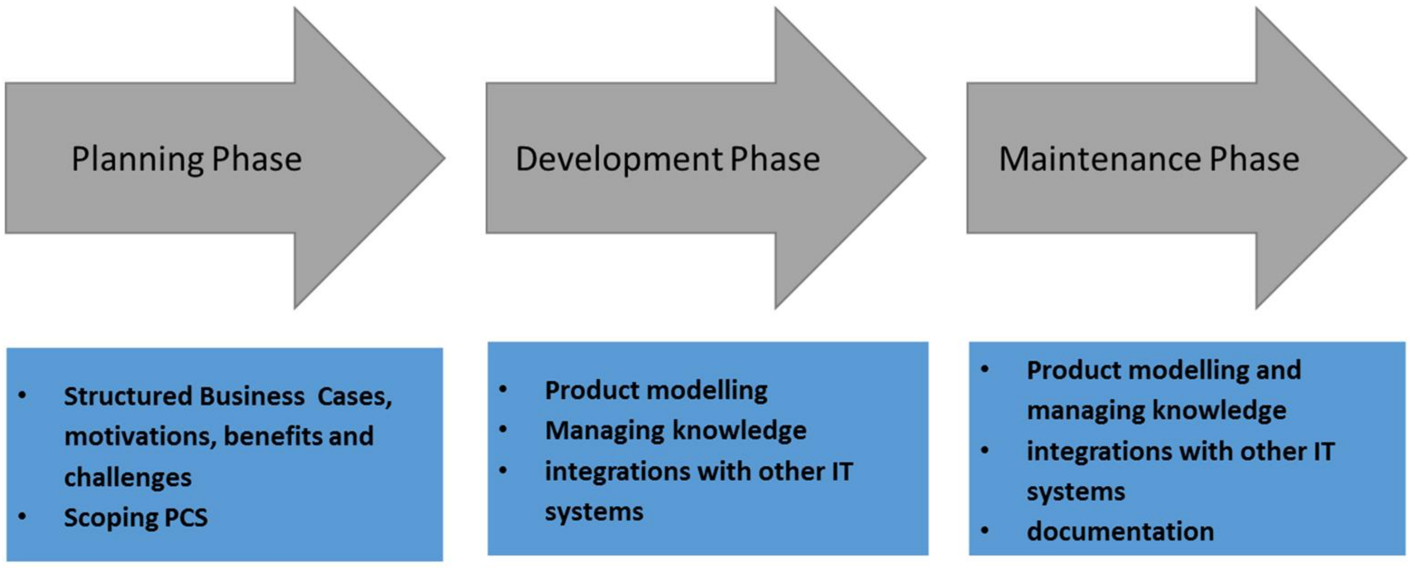


Figure 2-1 Research objectives for selected phases of PCS projects

The RQs targets: planning, scoping, knowledge management, maintenance and documentation, and further developments in PCS projects. Some of the RQs such as RQ1 and 2 belong to just planning phase, while some of them such as RQ3, 4 and 5 can have overlaps among different phases of PCS project. As an example in Figure 2-1, modelling and documentation could be covered in both development and maintenances phases. Integration with IT systems can take place both in development phase or as further developments in the maintenance phase.

RQ.1. How can PCS projects be planned?

Each of RQs (1, 2, 3, 4 and 5) focuses on the mentioned three different phases of the PCS management process to be considered in PCS projects. The first RQ refers to the phase before starting PCS projects or the initiation and planning phase.

RQ.1.1. How can we make a strategy to demonstrate different application of PCS projects?

The *RQ.1* can be broken down into three sub questions. The *RQ.1.1* aims to improve the strategical decisions for prioritizing PCS projects. This phase is strategically important in the companies for prioritization of the different projects as well as prioritization of the resources time for different tasks. A framework is proposed that aims to provide a structured approach to developing a strategy and guide the development and implementation processes of PCSs in ETO companies.

RQ.1.2. How can the benefits and challenges from different PCS projects be evaluated?

The *RQ.1.2* is how to determine the benefits, challenges and deliverables of the project. This phase is challenging as the criteria could determine the success or failure of the PCS. Demonstration different potential of PCS projects and quantifying them results in the most beneficial project selection for the company. *RQ.1.2* addresses the evaluation techniques and frameworks for determining the benefits and challenges from PCS projects which lead to a formulated planning phase.

To determine the benefits, the research captures this opportunity by quantifying the long-term cost savings produced by PCSs and compares it to the cost of development, implementation and maintenance of the system. The question asked specifically in the paper is as below:

What is the realized ROI for the case company's PCS over a five-year period?

The other research work asked questions about the motivations and benefits for implementing PCS. The research adopted in this paper is based on survey followed with interviews to answer the questions:

What are the main motivations industrial that companies consider for implementing PCSs to support their design and specifications processes?

How successful are companies in achieving benefits associated with the initial motivations described prior to the implementation of the PCSs?

The next paper identifies and categorizes the main challenges manufacturing companies face when implementing and utilizing their PCSs, and then assesses the importance of those categories, highlighting the specific challenges that can be found within each category. The questions asked regarding assessing challenges in PCS are as follows.

What are the main categories of challenges that manufacturing companies face when implementing and utilizing the PCSs?

What is the importance of each category of challenges that companies face when implementing and utilizing their PCSs?

Which specific challenges within each category do manufacturing companies face when implementing and utilizing the PCSs?

RQ.1.3. How can a standard business case for PCS projects be framed?

Answering the questions above will provide the inputs for BC for PCS projects. *RQ.1.3* reports the challenge of the unavailable framework for making BCs in PCS projects. The proposed structured BC framework can pave the way of quantifying motivations, benefits and challenges regarding the risks of the PCS project. The RQ is answered by reviewing the BCs frameworks for IT projects and determine a framework for PCS projects.

RQ.2. How can PCS projects be scoped?

RQ.2 refers to the lack of research on scoping PCS projects. The literature is reporting the gap for a structured framework and this research develops the framework by investigating different spread tools and methods for scoping PCS projects. To answer *RQ.*

2, all of the steps available in the literature for scoping PCS is taken into account and their sequence is determined and validated in the case company.

RQ.3. How can we acquire and manage knowledge needed for PCS projects?

RQ.3 targets one of the main challenges related to development, maintenance and documentations of PCS projects, which has been reported in literature for several years. In order to acquire sufficient level of relevant knowledge while managing the required level of details in PCS projects, a structured framework is needed. There are Knowledge Management (KM) frameworks for IT projects available and in this research work we adopt them for PCS projects.

RQ.4. How can the PCS projects be modelled and documented?

To model and document PCS projects is one of the main concerns in PCS projects and this research contribute to solve this challenge at the companies. *RQ.4* investigates the importance of modelling in PCS projects and illustrates the gap in the literature for having an agile automated documentation framework and tool.

RQ.4.1. How can we automate the documentation, validation and communication process in PCS projects?

In *RQ.4.1,* we took the opportunity to investigate about all available tools and methods in documentation and maintenance phase of PCS projects. The hesitation of practitioners to use documentation tools is reported in the literature. Furthermore, we try to contribute to theory and practice by proposing an agile automated documentation framework followed by an automated IT documentation system fulfilling the requirements for documentation in the case company.

RQ.4.2. How important is it to use the structured modelling and documentation techniques in PCS projects?

The *RQ.4.2* demonstrates the importance of documenting and modelling the knowledge of PCS in a structured way. To answer this question, a survey is conducted to evaluate the importance of available formal modelling techniques in PCS projects and is answering the following propositions:

> *The use of a formal modelling technique (CPM procedure) will result in improved control of product variants.*
>
> *The use of a formal modelling technique (CPM procedure) will result in the increased availability of product knowledge in organizations.*
>
> *The use of a formal modelling technique (CPM procedure) will result in increased employee satisfaction.*

RQ.5. How can the integrations with other IT systems lead to improvements in the performance of PCSs?

RQ.5 verifies that PCS performance increases when it is in integration with other IT systems across the supply chain. This means that connecting PCS to other internal or external IT systems increases the performance of PCS as it leads to automation in the processes. In this thesis, it is shown how to compare the similarities of the designed projects in another database and configured projects by internal integration. In another study, the importance of integration across supply chain is illustrated while PCS is integrated with suppliers' PCS externally.

Answering all the RQs and validating them is in need of designing the research in general and for each RQ. The following chapter shows the research method and the main stages of the PhD project.

2.2 Research methodology

This section explains the research design of the PhD project in general. This PhD project is based on the classification of various research studies.

2.2.1 Basic science research

Van de Ven (2007) proposes four different forms of engaged scholarship depending on the purpose of the research to examine basic questions of description, explanation, and prediction or applied questions of design, evaluation, or action intervention. As in Figure 2-2, Van de Ven (2007) defines these four forms as basic science research, collaborative basic research, design research, and action research. In *basic research,* the researcher is an outsider of the social system being examined, but solicits feedbacks from stakeholders. In *collaborative basic research,* the researcher and stakeholders share the activities such as: Research design, theory building, problem formulation and problem solving. The research teams are often composed of insiders and outsiders. *Design science research* is undertaken to examine the question and evaluate them as an outsider. *Action research* projects tend to begin by diagnosing the particular problem or need of one particular client.

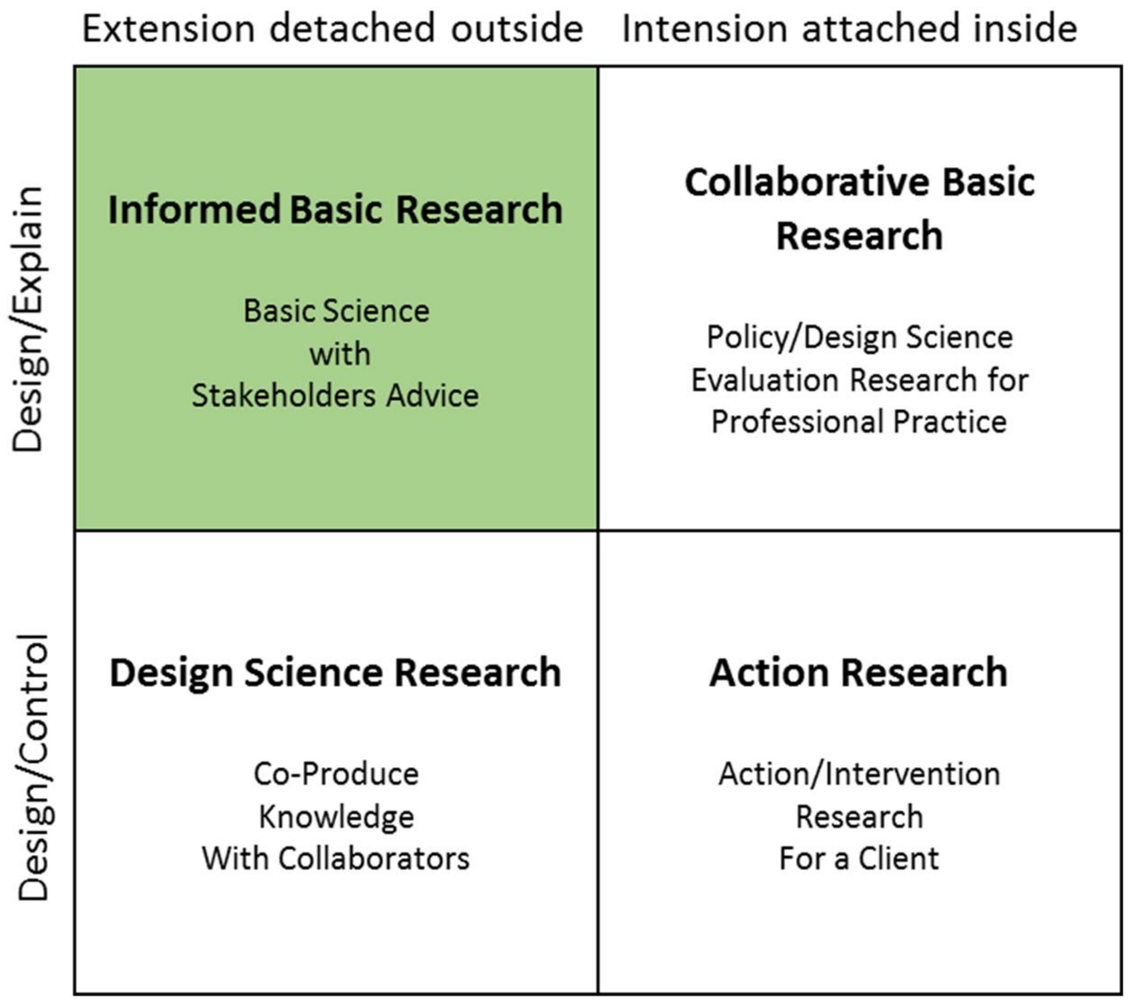


Figure 2-2 Different forms of engaged scholarship (Van de Ven, 2015)

This Ph.D. project is an industrial project and a basic science research in Haldor Topsoe A/S. According to Van de Ven (2007), basic science research is undertaken to describe or explain a social phenomenon where the researcher is a detached outsider of the social system being examined but solicits advice and feedback from key stakeholders and inside informants on the research. Moreover, I was involved in projects' planning, developing, implementing and maintaining as well as the overall managerial opportunity. As the project manager, I was involved in the change process in Haldor Topsoe in order to implement, test and launch the projects related to the PhD period. The Ph.D. research was examined and evaluated in Haldor Topsoe A/S along with other case studies in other industries. This helps in understanding the problem in different industrial settings and a detailed observation of lack of tools and frameworks. I had the outsider perspective while evaluating my different solutions inside Topsoe along with other case studies. Combining different observations and studies in different case companies as well as evaluation of the proposed frameworks and methods enrich the validity of research conclusions. At the same time, the research results are shared with the practitioners to be applied in the process of planning, developing, and documenting PCS projects.

2.2.2 Design research methodology

Based on the previous section, this PhD thesis is conducted as basic science research, which is determined where the research is located and how the researcher and industries are engaged. The Design Research Methodology (DRM) includes different steps that aim to formulate and validate proposed theories and methods.

The DRM framework presented by Blessing and Chakrabarti (2009) is used as a research framework for this PhD project. The main concept of the DRM framework is to view the research constant progress with specific objectives. The nature of this research methodology is heuristic, rather than algorithmic. The progress from one stage to another is not linear, while includes many iterations. Figure 2-3 provides a graphical representation of the DRM framework. The DRM framework is selected as it includes distinguished stages with specific goals. Moreover, this methodology assists the researcher to observe the current situation while moving towards the desirable future stage in an iterative process. The DRM framework also allows the evaluation of the suggested approach and its application. The findings are assessed and evaluated iteratively, which ensure the process of obtaining more valid results.

The DRM framework consists of four stages: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II (Figure 2-3). DRM guides the research Projects through these stages:

In the first stage, the Research Clarification (RC), the current situation and then the future aims based on the gaps and drawbacks of the current situation are discussed. Furthermore, the literature study is performed to find out the available solution and gaps in the literature. At this stage the preliminary goals and planning are made to support the future successes.

In the second phase, the Descriptive Study I (DS-I), further understanding and literature research are provided on a higher level of details and the goal of the study is elaborated. The factors influencing the current situation are examined and supported with empirical data.

In the third stage, the Prescriptive Study (PS), the scenarios can be developed based on the data and experiences. These scenarios address the challenges in the current situation.

In the last stage of the DRM, the Descriptive Study II (DS-II), the research method used to validate the result in this thesis are case studies. The outcome of the suggested scenarios is analysed. If the solution is not promising enough, the researcher returns to the DS-I stage to improve the factors and the assumptions, in order to re-evaluate the suggestions for improvement and consequently the results.

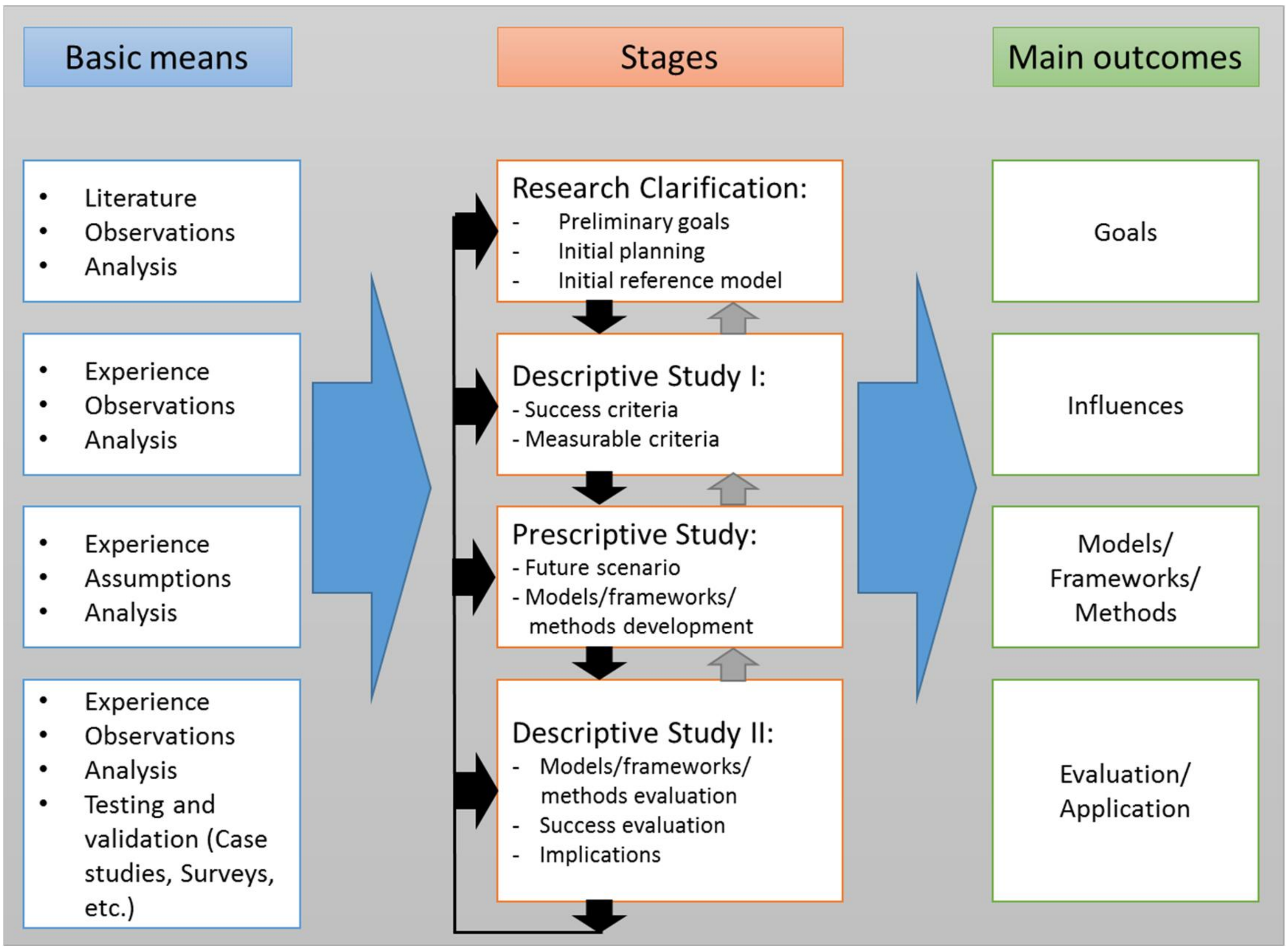


Figure 2-3 The design research methodology (DRM) adjusted from (Blessing and Chakrabarti, 2009)

2.3 Research plan

This chapter discusses each of the stages of the thesis which helps to view the research constant progress with specific objectives during the three years.

2.3.1 Research stages

Based on the first step of DRM (RC), the first step of the project is defined to identify the challenges in ETO companies while planning, developing, and documenting or even further developing PCS projects. Based on the available literature and the experience of working in industry, the realistic assumptions based on the gaps and problems are made. Part of RC is included in the first chapter of the thesis formulating problem statement. In this stage, a clear and deep understanding of the challenges in industry and academia is provided aligned with investigations regarding all the available tools and solutions. The main RQs and sub questions are formulated. The initial literature review is conducted to provide the understanding of the importance of PCS role in product customization and untangle some of the personalization challenges. The problem statement is based on the reported challenges in the different phases of PCS projects. The results of this stage are reflected in papers C and D in the Chapter 4. In Paper C, we are focusing on motivations in industrial applications of PCSs and we are evaluating the realized benefits throughout a survey. This study helps in realizing the expectation of the industry and how successful these companies are in achieving these benefits. Paper D has a comprehensive review on challenges related to PCS in different phases reported in the current literature. This paper provides a clear understanding of the impact of these challenges throughout a survey.

In the stage DS-I, empirical data is collected for further understanding of challenges in the PCS projects process from planning to the maintenance phase. Several phases of PCS projects lifecycle are taken into account for this research project. Empirical data is collected from industries via case studies and surveys. Paper B and I represent results of the analysis. In paper B, we are analysing ROI in a case company over a five-year period. Correlations between using the modelling techniques and their impact on PCS projects are discussed in Paper I based on the survey.

In the PS stage of the DRM framework, the focus of the research is to examine the factors, which have influences on PCS project process. Different frameworks for improving these stages are developed during this research. The first framework is related to strategies for demonstrating different application from PCS projects, which help in projects prioritization in Paper A. In Paper E a framework for BCs in PCS application area is discussed. Then, Paper F proposes a framework for scoping PCS projects throughout the lifecycle. Paper G and H suggest framework specifically for the knowledge management phase and documentation phase in PCS projects. Papers J and K discuss different steps of a standard framework to improve the applicability of PCSs in integration with other IT systems. In some of these papers, IT tools are also developed to validate the framework such as paper H and J and K.

The last stage of DRM framework, PS II, provides the testing and validations for the proposed frameworks and tools. In this PhD thesis, the validation is done through one or multiple case studies. Papers A, B, F, H, J and K focuses on one case company validation and papers E and G validate the data benefiting from multiple case studies. The case study is presented in all papers is Haldor Topsoe A/S. Other ETO companies are also used for providing further testing and validation for the proposed frameworks which help in generalizability of the solution. The other papers including C, D and I are based on a survey.

2.3.2 Case studies

Case study has consistently been one of the most powerful research methods in operation management, particularly in testing new theories (Voss et al., 2002). Case studies research is the most widely used qualitative research method in information systems research, and is well suited to understand the interactions between information technology-related innovations and organizational contexts (Darke et al., 1998). Moreover, lack of maturity in this research field makes the study suitable for case studies.

The case study method could support the objective of this thesis while answering the “how” and “why” questions. The case study comprises all-encompassing methods, covering the logic of design, data collection approaches, and data analysis techniques (Yin, 2013).

Inductive case based researches have been used both for hypotheses testing and to develop new theories. However, when conducting multiple case studies in this type of research, attention has to be given to the data triangulation as well as observer triangulations (Creswell and Clark, 2007; Johnson et al., 2007; Yin, 2013). Multiple benefits can be gained from triangulations such as: complementary insights, which add firstly to the richness and the convergence of observations which enhances the confidence in findings. For example, interviews can be conducted by two persons, with one researcher handling the interview questions, while the other recording notes and observations (Eisenhardt, 1989).

2.3.2.1 Cases and unit of measurement

The empirical foundation in this research is based on several case studies and surveys/interviews with the relevant companies. In this study, different case studies considered while collaborating with other researchers in the area. The vast majority of the case companies are providing chemical and mechanical products and services. Another important factor is that all companies have a strong interest in research and development, especially within the area of PCS projects. All of them already use PCS in sales and production process. Finally, all of the cases are similar in reporting the challenges related to planning, developing, implementing and maintaining PCS project. All of the case companies are discussed elaborately in each of the specific papers that are provided in Appendix chapter. In Table 2-1, a list of the case companies used in the case studies papers is provided. The first column is the number of case company to ensure the anonymity. The second column provides the information about the type of industries. The next column shows the papers that used this case company as the empirical foundation. The last column shows the relevant RQs discussed in section 2.1 and the connection between different case studies, papers and RQs are provided.

The unit of analysis is normally the PCS projects as the RQs are based on the different phases of the projects. Testing PCS projects in different industrial setting help in evaluating the solution across the companies.

Table 2-1 Overview of the case companies

Case company	Product / Industrial sector	Papers	RQ.
I	Chemical/ Mechanical	1, 2, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 21, 22 (A, E, F, G, H, J)	1, 2, 3, 4, 5
II	Mechanical/ Chemical	14, 15, 19, 21 (G, H)	3, 4
III	Mechanical	3, 4, 19, 21, 23 (B)	1, 4, 5
IV	Mechanical / Chemical	7, 11, 19, 21	1, 4
V	IT systems/ Services	19, 21	4
VI	Mechanical / Electrical	21	4

2.3.3 Surveys

As mentioned before about the data triangulation, the use of different types of data and methods provides richer and stronger evidence to support the findings of a study (Yin, 2013). This study mainly builds on qualitative data and qualitative data mostly collected through interviews and observations. For the quantitative data, one survey designed in order to have a deep understanding of the benefits and challenges of PCS project and compare the results with the literature. In the same survey, we asked questions regarding the modelling techniques in use and the effect of it on the PCS projects process. This survey combines mail and phone administration.

2.3.3.1 Population and sampling

The criteria for selecting the companies for the study was manufacturing companies that provide customized or engineered solutions with experiences of using configurators to support their specifications processes. Brainstorming sessions were conducted to identify additional companies such as those involved in consultancies, vendors of configurators, and collaborating companies. Additional companies were also identified in the interviewing process, when the respondents were asked for a reference list of other companies that might fulfil the criteria to participate in the research. In total, 26 companies fulfilling the selection criteria were contacted. The sample companies represent small, medium, and large manufacturing companies providing customized and engineered solutions. The levels of customization and complexity of the offered products varies greatly among the companies, ranging from equipment and components to complete plants. Only one person from each company was responsible for answering the survey. The contact person at each company was selected based on their familiarity with the PCS projects, irrespective of their formal role at the company, because in-depth knowledge of the configurators was required, which the top-level management at the companies might not possess.

2.3.3.2 Data collection and data analysis

The data collection is conducted in two phases: (1) a pre-study phase to test the questionnaire, and (2) the interview phase to collect the data for analysis. The pre-study phase aims to validate the questionnaire and its administration procedure. Therefore, three pilot interviews were conducted to test the applicability of the questionnaire in different types of industrial configuration settings. The next step involved e-mailing the questionnaires to the respondents with a description of the purpose of the study, the interview procedure, and a follow up notification, and appointments were made for phone interviews. The phone interviews were conducted as a walkthrough of the questionnaire. The interview process allows clarification and elaboration of the responses to ensure a correct and consistent interpretation of the questions and to ensure that the interviewer gained a complete understanding of the company's setting.

In the analysis phase, the answers to the questionnaire and the interviews were entered into an MS Access database, crosschecked for data entry errors, and analysed. The answers from the open questions were coded and grouped into categories according to the nature of the answers. To prevent bias from the interviews, the data were coded and analysed by a different person to the one who collected the data.

2.3.4 Communication of the research

The following articles provide the contribution to this research project. The articles are coded alphabetically from A to K, are selected among around 24 articles as the main contributions of these three year of research. The reason for not using all the articles in thesis structure is to make the concept clear, transparent and avoid confusion while summarizing. All the articles are submitted to academic journals and conferences within the field of PCS. The selected articles are related specifically to the RQs and discussed elaborately in Chapter 4 and the full articles are appended in the end of this dissertation.

As illustrated in Table 2-1, the case studies used in different articles are clarified. Papers C, D and I are survey papers and then they are not related to the case study research.

Table 2-2 Overview of publications

RQ.	Number	Journal /Conference	Papers in the result chapter	Articles
Planning PCS (Strategy, benefits, challenges, and business cases)	1	Journal	A	Kristjansdottir, K., Shafiee, S., Hvam, L., & Haug, A., (2017). How to Identify Possible Applications of Product Configuration Systems in Engineer-to-Order Companies. Journal of Industrial Engineering and Management, V. 8, No.3.
	2	Conference	—	Kristjansdottir, K., Shafiee, S., & Hvam, L. (2016). Development and Implementation Strategy for Product Configuration Systems in Engineer-to-Order Companies. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),* Bali, Indonesia.
	3	Journal	B	Kristjansdottir, K., Shafiee, S., Hvam, L., Myrodia, Anna & Bonev, M. (2017). Economic Value Creation from Using Product Configuration Systems – A Case Study. Submitted Journal article.
	4	Conference	—	Kristjansdottir, K., Shafiee, S., Hvam, L., Bonev, M., & Myrodia, A., (2016). Quantification of benefits and cost from applying product configuration systems. *7th International Conference on Mass Customization and Personalization in Central Europe (MCP – CE 2016),* At Novi Sad, Serbia.
	5	Conference	C	Kristjansdottir, K., Shafiee, S., & Hvam, L. (2016). Industrial application of configurators: From motivations to realized benefits. *18th International Conference on Industrial Engineering,* Seoul, Korea.

RQ.	Number	Journal /Conference	Papers in the result chapter	Articles
	6	Conference	—	Kristjansdottir, K., Shafiee, S., & Hvam, L. (2015). Utilizing product configuration systems for supporting the critical parts of the engineering processes. *2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), (pp. 1777-1781),* Singapore.
	7	Conference	—	Kristjansdottir, K., Shafiee, S., Hvam, L., & Bonev, M. (2015). Identification of Profitable Areas to Apply Product Configuration Systems in Engineer-To-Order Companies, *2015 World Conference on Mass Customization, Personalization, and Co-Creation,* Montreal, Canada.
	8	Journal	D	Kristjansdottir, K., Shafiee, S., Hvam, L, and Forza, C. (2017). The main challenges for manufacturing companies in implementing and utilizing configurators. Submitted Journal article.
	9	Journal	E	Shafiee, S., Kristjansdottir, K., & Hvam, L. (2017). How to frame business Cases Framework for Product Configuration system Projects. Submitted Journal article.
	10	Conference	—	Shafiee, S., Kristjansdottir, K., & Hvam, L. (2016). Business cases for product configuration systems. *7th international conference on mass customization and personalization in Central Europe,* Novi Sad, Serbia.
	11	Conference	—	Myrodia, A., Kristjansdottir, K., Shafiee, S., Hvam, L. (2016). Product configuration system and its impact on product's life cycle complexity. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),* Bali, Indonesia.
Scoping PCS	12	Journal	F	Shafiee, S., Hvam, L., & Bonev, M. (2014). Scoping a Product Configuration Project for Engineer-to-Order Companies. International Journal of Industrial Engineering and Management, 207-220.
	13	Conference	—	Shafiee, S., Hvam, L., & Bonev, M. (2014). How to scope a product configuration project in an engineering company? *6th International Conference on Mass Customization and Personalization in Central Europe,* Novi Sad, Serbia.
knowledge management in PCS	14	Journal	G	Shafiee, S., Kristjansdottir, K., & Hvam, L., Forza, C. (2017). How to scope configuration projects and manage the knowledge they require. In the second round of revision in International Journal of Knowledge Management.
	15	Conference	—	Shafiee, S., Hvam, L., & Kristjansdottir, K. (2015). Goal-Oriented Data Collection Framework in Configuration Projects. *2015 World Conference on Mass Customization, Personalization, and Co-Creation,* Montreal, Canada.

RQ.	Number	Journal /Conference	Papers in the result chapter	Articles
Modelling, documentation, and maintenance of PCSs	16	Journal	H	Shafiee, S., Hvam, L., Haug, A., Dam, M., Kristjansdottir, K. (2017) The documentation of product configuration systems: A framework and an IT solution. Journal of Advanced Engineering Informatics, doi:10.1016/j.aei.2017.02.004, V.23, pp. 163–175.
	17	Conference	—	Shafiee, S., Hvam, L., & Kristjansdottir, K. (2015). An agile documentation system for highly engineered, complex product configuration systems. *22nd EurOMA Conference,* Neuchâtel, Switzerland.
	18	Conference	—	Shafiee, S., Kristjansdottir, K., & Hvam, L. (2015). Alignment of Configuration and Documentation for Highly Engineered Complex Product Configuration Systems: a Demonstration from a Case Study. *IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT) (Vol. 3, pp. 249-250),* Singapore.
	19	Conference	—	Shafiee, S., Kristjansdottir, K., & Hvam, L. (2016). Industrial experience from using the cpm-procedure for developing, implementing and maintaining product configuration systems. *18th International Conference on Industrial Engineering,* Seoul, South Korea.
	20	Journal	I	Hvam, L.; Kristjansdottir, K.; Shafiee, S.; Mortensen, N.H. (2017), Product configurators: A study of the impact of applying IT formal product modelling techniques. In the third round of revision in International Journal of Production Research.
	21	Conference		Shafiee, S., Kristjansdottir, K., Hvam, L., Felfernig, A., & Myrodia, A. (2016) Analysis of Visual Representation Techniques for Product Configuration Systems in Industrial Companies. *IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),* Bali, Indonesia.
PCSs in integration with other IT systems	22	Journal	J	Shafiee, S., Kristjansdottir, K. & Hvam, L, (2017). Automatic Identification of Similarities across Products to Improve the Configuration Process in ETO Companies. International Journal of Industrial Engineering and Management, V. 8, No.3.
	23	Conference		Shafiee, S., Hvam, L., & Kristjansdottir, K. (2015). How to Analyze and Quantify Similarities between Configured Engineer-To-Order Products by Comparing the Highlighted Features Utilizing the Configuration System Abilities. *17th International Configuration Workshop (pp. 139-145),* Vienna, Austria.
	24	Conference	K	Kristjansdottir, K., Shafiee, S., Bonev, M., Hvam, L., Bennick, M.H., &Andersen, C.S., (2016). Improved performance and quality of configurators by receiving real-time information from suppliers, *Configuration Workshop,* Toulouse, France.

In order to make it easier to find the relevant papers related to RQs, Figure 2-4 illustrates the papers used in the result chapter and color-coded to facilitate the search for relevant RQs.

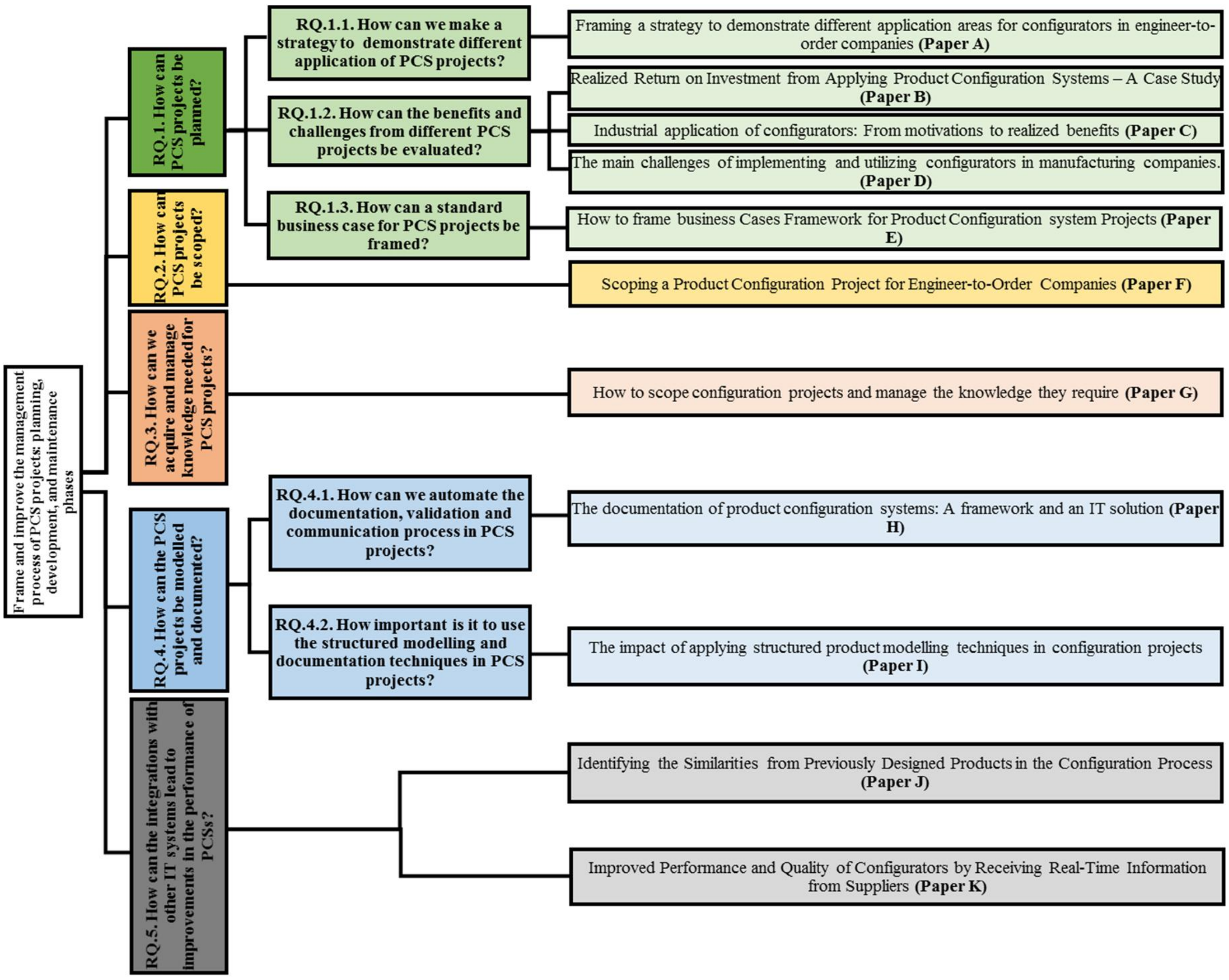
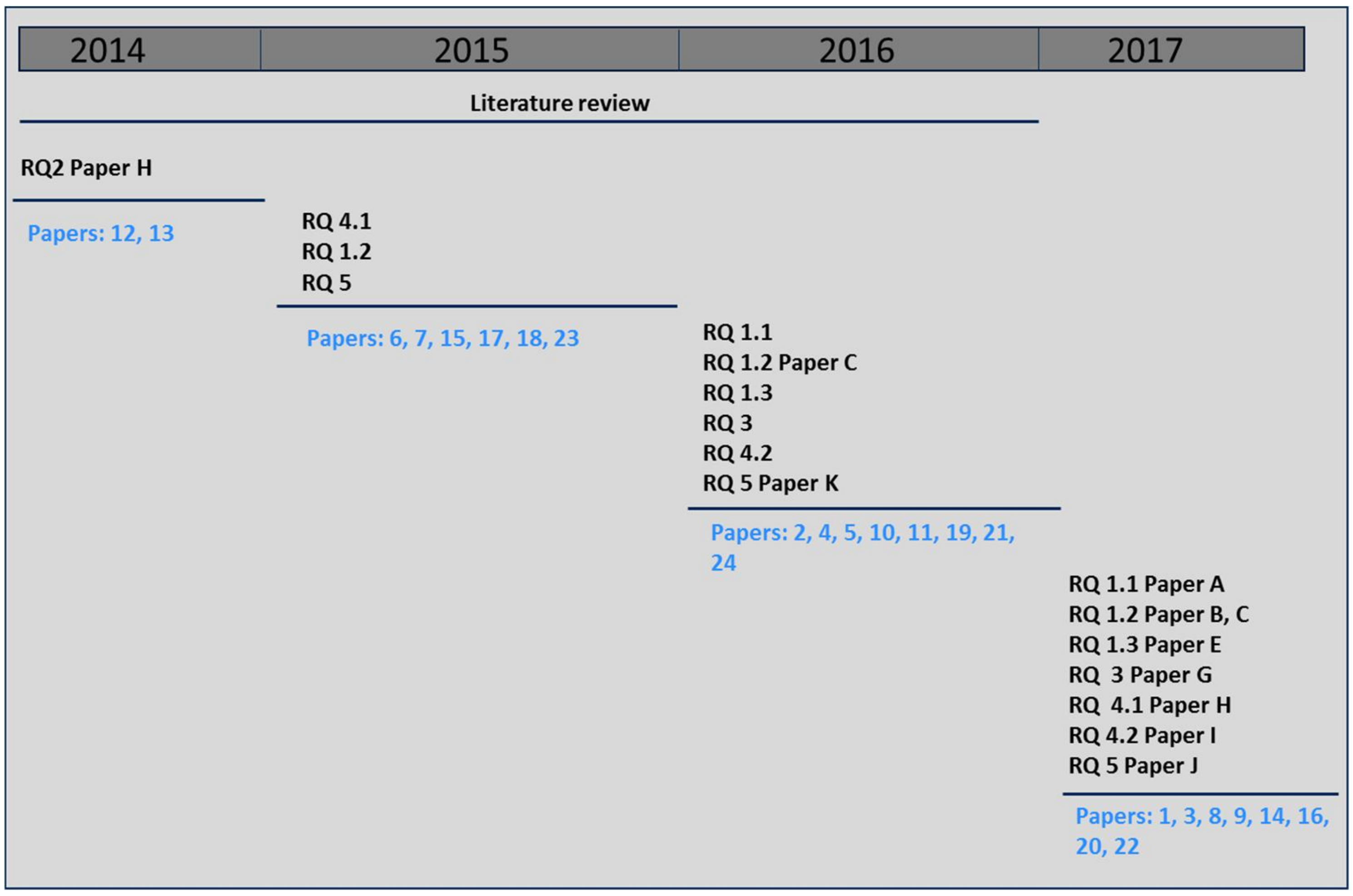


Figure 2-4 Link between papers and research questions

2.3.5 Scheduling the research

In order to have a clear understanding of the timing and schedule planning during the PhD project, the Gantt table in Table 2-3 is considered. The table illustrates the RQs and published papers planned over the time. As it is demonstrated in 2014, the PhD focus is RQ 2 and scoping, while in 2015, RQ1, 4, and 5 are explored by conference papers. In 2016, The PhD focus area is covering almost all the RQs due to the experiment gained by working on different PCS projects and dominant on the literature. The focus in 2017 is to wrap up all the gathered empirical data and concentrate on writing and publishing the knowledge during the past years.

Table 2-3 Gantt table of PhD schedule



2.4 Chapter summary

The first section of this Chapter discusses the five RQs which will be answered during the three years of PhD. These five RQs cover three different phases of a PCS project including planning, developing and documenting. The answers to RQs aim to propose solution for the challenges reported during the PCS projects supply chain. This research is structured based on DRM framework as it consists of distinct stages; each of them sets specific goals and iteration among different stages. DRM enables the researcher to set clear goals and criteria for achieving and evaluating the success of the suggested solution. Moreover, the factors that influence the current situation towards the future desirable state are defined and the impact they have on the success is assessed. The DRM framework also allows the evaluation of the suggested approach and its application, as it enables an iterative research process. During the iterations, the findings are assessed and evaluated, to ensure the process of obtaining more valid results. The application evaluation achieved through collaborations with other companies and practitioners. The empirical foundation in this research work is based both on one to multiple case studies. Inductive case based researches have been used both for hypotheses testing and to develop new theories.

The Table 2-2 illustrates the list of publication during the PhD while marking the main contributions used for this thesis. RQs and the papers are numbered, while the papers used in the PhD thesis are marked alphabetically. As explained, the reason for not using all the papers is to keep the thesis as a summarized focused report. The time schedule for managing and planning different publication in answer of different RQs is discussed as the final chapter.

3 THEORETICAL FRAMING

This chapter establish the main ground of theoretical background of the PhD study. The chapter introduces the topic of PCS to address the key challenges in ETO companies. Specific questions are formulated to narrow down the scope of the research project. This chapter describes the basic concepts of some of the reported challenges in PCS projects which lead to the contributions in this PhD thesis. The literature review presented in this chapter is taken from the articles in the Appendix. Section 3.1 discusses the differences between IT and PCS projects. These differences clarify the problem statement and why we need to contribute to PCS area and separate PCS projects from IT projects. Sections 3.2 and 3.3 explain the concept of strategies and motivation for investment in PCS projects and the need for a structured framework in the literature. The requirements for BCs in PCS project is discussed in section 3.4. In section 3.5, the scoping of PCS and how literature contributes to the concept is discussed. The knowledge management challenges and available literatures is discussed in section 3.6. Section 3.7 refers to the available modelling techniques in literature as one of the important topics in PCS projects. This section describes the importance of documentation in PCS projects and how other researchers contribute so far. The importance of the integrations between PCS and other IT systems are discussed based on the available literature in section 3.8. The last part of this chapter summarizes the discussions.

3.1 Differences between IT and PCS projects

There are several differences between IT projects and PCS projects compared to other IT projects as the reasons for having a separate research area for PCS (illustrated in Figure 3-1).

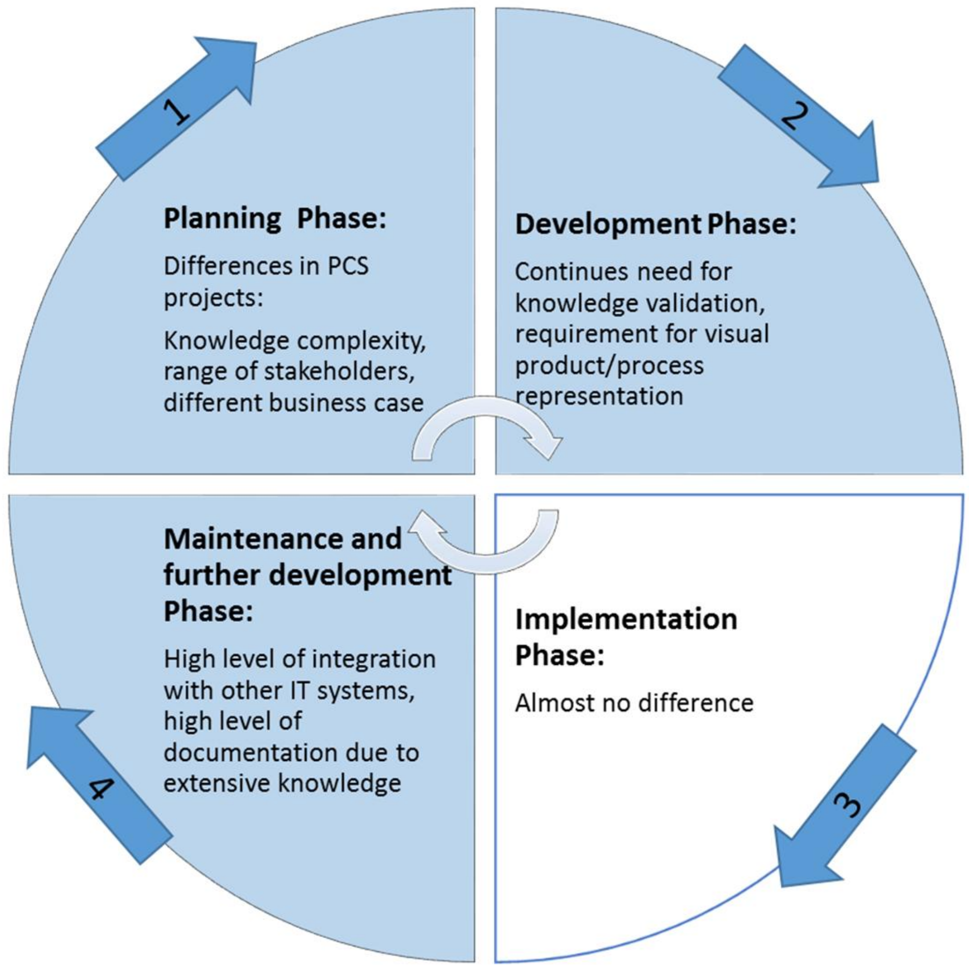


Figure 3-1 Different phase of PCS projects and differences from IT projects

Because of the knowledge complexity and extensions in PCS, it is essential to determine the scope of the project in the early phases in order to determine the entire flow of the project. This is done by identifying the requirements, evaluating the time and budget, and prioritising the different products and functions depending on the variety and complexity of the knowledge, the required tasks and the resources for the project development (Shafiee et al., 2014). The scope of IT projects is determined differently because not all of them necessarily involve with extensive product knowledge. In PCS projects, goals and stakeholders' requirements from the first steps have to be clarified; due to the complexity of the involved knowledge, the range of stakeholders, and special system requirements (Studer et al., 1998).

The second difference relates to the details of each step required for PCSs compared to IT projects. Because of the differences in the nature of the received knowledge, PCSs are formalised, combined, modelled and communicated differently from IT projects. Consequently, the knowledge modelled in PCSs is extensive and has to be continually validated by domain experts (Basili and Weiss, 1984). Strong communication between the configuration team and domain experts in PCSs is vital, and specific modelling techniques tend to solve this challenge in PCSs (Forza and Salvador, 2002b). Additionally, without proper validation, very minor misunderstandings in the knowledge could lead to big errors in the calculations and outputs.

The third difference relates to the need for specific comprehensive documentation and maintenance of the knowledge in PCSs (Haug and Hvam, 2007). The knowledge has to be clear and understandable to all stakeholders in non-IT language for many reasons. For example, there is a high level of integrations with other IT systems, and the knowledge must be shared among participants in the supply chain. In addition, the frequent changes in product knowledge necessitate continual updating and maintenance of the knowledge (Tiihonen et al. 1996a; Alexander Felfernig et al. 2000; Friedrich et al. 2014). By contrast, the documentation in IT projects normally is a summarised explanation of the codes and a set of user stories that are passed on to another IT specialist (Coram and Bohner, 2005). Most IT projects are not required to work with complicated products or process knowledge, and IT specialists do not have to communicate with people outside of the IT field for verifying the contained knowledge in the system. Furthermore, the knowledge required for IT projects does not have to be updated constantly (Coram and Bohner, 2005).

Also, in PCS projects, there is a high level of integrations with other IT systems (Felfernig, Hotz, et al., 2014), which implies a particular need for IT development, testing, and collaborations. Most often, PCS projects become more expensive and time-consuming than anticipated in the development phase, which may be explained by the complexity of the involved knowledge, the range of stakeholders, special system requirements, specific risks and different cost estimations (Hvam et al. 2008; Studer et al. 1998).

In summary, the phases in IT project management differ from that in PCS project management. The only step which is as challenging in PCS as in IT projects is the implementation phase. This phase involves with organizational challenges and change management principles which is the same for all kind of IT projects. However, owing to knowledge complexity and variety in stakeholders' range in PCSs, the frameworks for IT projects are not suitable for PCSs because they fail to incorporate sufficient steps to cover all the needs in PCS projects.

3.2 Strategies for PCS Projects

Different authors have proposed frameworks to guide the development of configurator projects. Haug et al. (Haug et al., 2012b) have defined strategies for configurators in ETO companies by focusing on the involvement of different specialists in the development and implementation processes. These specialists are grouped into product experts, knowledge representation experts and configuration software experts. This study discusses the strengths and weaknesses of various development strategies in relation to the different expertise involved. However, it does not describe how projects are selected and focuses instead on the actual development process. Felfernig et al. (Felfernig et al., 2001) also proposed a development strategy based on the standard Unified Modelling Language (UML) design language to develop and cope with increasing complexity in the knowledge base. The three main components of the configuration environment were: knowledge acquisition, configuration and reconfiguration. The authors proposed diagnoses at each stage (Felfernig et al., 2001). which included an analysis and redesign of business processes, modelling of the product range, selection of configurator software, and modelling, implementation and maintenance of the plan. Forza and Salvador (Forza and Salvador, 2007b) provided guidelines for the implementation of configurators, which included benefit and cost analyses, planning of the implementation processes and aligning the execution of the implementation with best practices. Therefore, Hvam et al. (Hvam et al., 2008) and Forza and Salvador (Forza and Salvador, 2007b) both provided complete frameworks that described the different processes involved in configuration projects. However, in ETO companies there is often high product complexity and variety, which means there is an additional need to create a strategy to guide the future development and implementation processes.

3.3 Benefits from using PCS

The focus of this subsection of literature review is on the motivations and the benefits described in the literature in relation with PCS. This section is the basic of realizing and assessing requirements for BCs.

Aldanondo et al. (2000) describe how PCSs can be used in industries providing highly customized products, where there are iterative steps resulting in long cycle time, risk of wasted time and money if the customer rejects the solution, risk of the proposed solution to be unfeasible, and finally the inaccurate cost estimation. Ardissono et al. (2003) propose a PCS services to support diverse customers in open market environment and to be able to integrate with suppliers providing configurable sub-products. Ariano & Dagnino (1996) present a case study based on a manufacturing furniture company. The main objectives of the implementation of the system are described in terms of providing a system that enables the employees to enter an order in quick and accurate manner, provide the mechanism to check the PCS and finally generation of BOM and drawings. Barker et al. (1989) present a case where the initial purpose of the PCS was to help employees in the manufacturing to validate the technical correctness before production. Fleischanderl et al. (1998) present a case where a PCS is applied in the complex domain of telephone switching systems. The system supports number of stages of the products' life cycle that includes sales, engineering, manufacturing, assemble and maintenance. It is claimed that the system has archived positive return of investment in the first year. Forza & Salvador (2002) present a case study where the introduction of the PCS has positively affected the sales, design, engineering and manufacturing processes at the company. The benefits of using the PCS are described in terms of errors generated in the sales processes are almost eliminated as a result to an automatic validity and completeness check performed by the PCS. Furthermore, the time for generating proposal and consequently the man-hours reduces significantly. In another study, Forza & Salvador (2002) introduce a case company faced with challenges regarding performance of correctness check of the products' specifications without increasing the control cost and reducing product variety. In the next study Forza et al. (2006) present a company that implemented a PCS and implemented a different product strategy that involved postponement of product differentiation. Haug et al. (2011) presents a study where fourteen companies are analysed in order to evaluate the impact from implementing a PCS on the lead-time for generating quotes and detailed products' specifications. Heatley et al. (1995) present a study where PCS rator is used to support operational tasks at a company. Initially the system was implemented to support the ordering process, where errors were generating that caused delays, threatened the overall quality, cost and the customers' satisfaction. By implementing the PCS, the correctness and completeness of the orders was significantly improved. Heiskala et al. (2005) performed a study to analyse the benefits and challenges of MC, configurable products, and PCSs with a special focus on services. The main benefits are described in terms of suppliers and customers. Hvam et al. (2004) present a case study where a company is faced with changed market environment, and increased pressure to deliver in shorter time, with lower cost and improved overall performance. Hvam et al. (2013) present a study where they describe the observed benefits from applying PCSs in four industrial companies. The result presented shows that lead-time has been reduced by 94-99%, on-time delivery is improved to be 95-100% and resources for making the specifications have been reduced by 50-95%. Petersen (2007) focus on the benefits in engineering companies from implementing a PCS. Sviokla (1990) presents the case where, the required demand for flexibility, constant new product development, great number of possible configurations the company was lacking overview resulting in number of errors. Tiihonen et al. (1996) present the main motivations for implementing a PCSs described in terms of being able to transfer up-to-date information to the sales units and enable them to use it in the right ways, and by increasing atomization by use of PCSs the numbers of errors should be reduced leading to improved quality. Trentin et al. (2012) explore the impact from using PCSs on products quality. Finally, Yu & Skovgaard (1998) present a study of a PCS tool where the aim are to guarantee the correctness of the configurations, ensuring consistency, handling constrains, overcome limitations with regards to maintainability and finally to support the use of configuration application in a user-friendly manners.

The discussed literature describes the various benefits that can be achieved in industrial settings from implementing a PCS. In few of the research the initial motivations for the implementation of the PCSs are addressed.

3.4 Business cases in PCS and available tools

Although the PCS literature does not in a detailed manner deal with the definition of BCs, some of the aspects that involve BC have been described. Based on literature, the main steps for BCs for IT projects can be described in terms of: 1) benefit analysis, 2) stakeholder's analysis, 3) IT requirements, and 4) risk and cost analysis (Gambles 2009; Ashurst et al. 2008; Häkkinen & Hilmola 2008;McNaughton et al. 2010). The literature of PCS projects reflects these aspects in some way, however there is a need both from academia and practitioners to combine these tools and methods in a framework.

Benefit analysis is a vital challenge for PCS projects as it determines the requirements of the project and shed light into project scoping (Hvam et al. 2008; Shafiee et al. 2014). There are goals mentioned for PCS projects in general (Petersen 2007; Ardissono et al. 2003), while different projects have different main goals. The goal of the project normally determines the expected outputs from the PCS project, helps in managing the knowledge, and determines the stakeholders (Mortensen et al. 2011; Heiskala et al. 2007; C. Forza & Salvador 2002; Salvador & Forza 2007; Felfernig et al. 2014).

Furthermore, *stakeholders' analysis* which means the users' expectations and requirements for the system, increases as PCS projects become more successful and popular among users (Barker et al., 1989). Stakeholders' analysis for PCS projects is also normally mentioned as one of the difficulties as the stockholders are varying and have different expertise (Forza and Salvador, 2002a). Determining the stakeholders and analysing their requirements before starting the projects leads to the right decisions which leads to time and resource saving (Felfernig, Hotz, et al., 2014; Mortensen et al., 2008; Salvador and Forza, 2007; Shafiee et al., 2014).

Process analysis is one of the major steps before initiating PCS projects, where the sales and engineering process are redesigned to increase efficiency by the help of PCSs (Forza and Salvador, 2002a). This typically involves analysing the current processes and redesigning the future processes. Future process analyses IT architecture and requirements if needed. Gap analysis is then used to measure the performance of the current process and set goal for the target performance. Furthermore, the GAP analysis can be used to see how the different scenarios contribute towards the targeted performance (Hvam et al., 2008; Tidstam and Malmqvist, 2011).

Cost and risk analysis are carried out to compare the different scenarios. In the literature, the cost estimation for evaluating the savings from PCS and further sensitivity analysis has been conducted (Kristjansdottir et al., 2016). Different authors are recommending tools such as sensitivity analysis for analysing the costs and risks of PCS project before the planning phase. These risks are categorized for PCS in literature (Hvam et al., 2008).

3.5 Scoping in PCS projects

As illustrated in Table 3-1 the literature provides input of parts of the scoping, however no scholars have provided a complete framework for how to scope a PCS. There are different steps for scoping PCS in literature which are the column in Table 3-1 and these different steps are: 1) aims and goals of PCS, 2) identification of stakeholders and their requirements, 2) objectives of the PCS, the IT-architecture (inputs, outputs, integrations etc.), 4) products and product features to include and a 5) project plan.

Table 3-1 Approaches to PCS scoping

Concepts	1 Aims and purposes of the PCS: PCS Benefits	2 Stakeholders' requirements	3 IT structure: Input / Output Managing and UI	4 Products' features: Level of details	4 Products' features: updating and maintenance	5 Project plan: Modelling techniques	5 Project plan: RUP
Hvam et al. (2008)	X			X		X	X
Forza et al. (2007; 2002)			X		X		X
Salvador et al. (2004)	X						
Mortensen et al. (2011)	X	X					X
Haug et al. (2007)			X	X		X	X
Ladeby et al. (1998)	X						
Blecker et al. (2004)	X						
Tidstam et al. (2010)							X
Jannach et al. (2013)			X	X			
Dvir et al. (2003)		X					
Felfernig et al. (2014; 2000)			X	X		X	
Trentin et al, (2011; 2012)	X						
Tiihonen et al. (1998)			X	X		X	X
Sabin et al. (1998)	X		X				
Jinsong et al. (2004)			X				

3.6 Knowledge management in PCS projects

The increased complexity of products increases the number of product features to be modelled and maintained in the PCS (Ardissono et al. 2003); thus, the configuration knowledge for different parts of the products is often spread among various experts within the companies (Hvam et al., 2008). Other valuable sources of knowledge are also available in internal software systems such as Enterprise Resource Planning (ERP) systems, calculation systems and spreadsheets (Friedrich et al., 2014). Therefore, early in the development phase of a configuration model, a knowledge acquisition and cleansing stage is required to centralise, model and formulate the product or process the knowledge (Felfernig et al. 2014). Knowledge management (KM) in PCS is one of the most time-consuming tasks for the domain experts[1] and the configuration team[2]. KM can be defined as an integrated process incorporating a set of activities to create, store, transfer and apply knowledge to a knowledge business value chain (Aurum, et al., 2008). Effective KM facilitates the creation and integration of knowledge, minimizes knowledge losses and fills knowledge gaps throughout the project (Lech, 2014). As Table 3-2 shows, many authors have discussed different steps but none have proposed a framework that incorporates the steps in sequence.

Table 3-2 Literature base for the main steps in the KM in PCS

Author (year)	Determining the scope of the PCS	Knowledge Acquisition	Modelling and Knowledge Validation	Documentation and Maintenance
Forsythe et al. (1989)	✓			
Tiihonen et al. (1996)		✓		
Sabin et al. (1998)			✓	
Aldanondo et al. (2000)			✓	
Chao et(2001)			✓	
Forza et al. (2002)				✓
Ardissono et al. (2003)		✓		
Margo et al. (2003)			✓	
Tseng et al. (2005)			✓	
Jinsong et al. (2004)		✓	✓	

[1] The experts who provide domain knowledge of the process of performing the task and the data content, as well as quality assurance, verification support (Barker et al., 1989).

[2] The team working on configuration projects include knowledge engineers, modellers, developers and project managers (Hvam et al., 2008).

Author (year)	Determining the scope of the PCS	Knowledge Acquisition	Modelling and Knowledge Validation	Documentation and Maintenance
Forza et al. (2007)		✓	✓	✓
Hvam et al. (2008)	✓	✓	✓	
Mortensen et al. (2008)	✓			
Haug et al. (2009)			✓	✓
Yang et al. (2009)			✓	
Hansen et al. (2012)			✓	
Felfernig et al. (2014)	✓		✓	
Shafiee et al. (2014)	✓			

3.7 Modelling in PCS projects

Modelling is the product language by which the designer or product developer can elaborate, evaluate and communicate (Andreasen, 1994). The goals of design research are not to develop as many different tools and models as possible (Gill, 1990), but to create a coherent set of tools and models with a universal terminology and theory basis. Product Modelling is a high level concept for modelling created in relation to development of a product, defining of the product, or communication about the product (Krause, 1988). Tomiyama defines that “Modelling is a process in which observed facts are filtered by a theory” (Tomiyama et al., 1989).

The literature has been discussed in the table has been divided into five main groups in Table 3-3. The first group called product architecture representation can be conceptual or visual and can contain different levels of formalization which is measuring the relevance of the mentioned product architecture representation to product configuration field. Formalization simply is the success of the modelling technique while representing the product knowledge. The second category is modelling tool aspects and the method part containing the information about the utilization of specific methods in the field of modelling. The next field is about IT support involved in product modelling and the validation and diagnosis part is implying to the research works which using methods for the validation the data used in the product modelling. Modelling focus is referencing the papers which are doing the modelling from the product aspect or the process aspect or even both of them. The case study part is referring to the papers which are conducting the case study research study. The target group is referring to the target group in the industry who are supposed to use the modelling. If the target group is the domain expert, it means that the modelling should be in an understandable language in order to make the communication process simpler. A configuration group within a company can do the modelling in IT language and use it internally inside the configuration team as well.

Table 3-3 literature results for modelling techniques

	Product architecture representation			Modelling tool aspects		Modelling focus		Case Study		Target Group	
Contribution	Conceptual	Visual	Level of Formalization	Methods	Computer support	Validation and diagnosis	Products	Process	Industrial application	Domain Experts	Configuration group
(Andreasen, 1980)	✓	✓	0	✓						✓	
(Aldanondo et al. 2000)	✓	✓	5		✓		✓	✓	✓		✓
(Soininen et al., 1998)	✓	✓	5					✓			✓
(Haug and Hvam, 2007)	✓	✓	5	✓	✓		✓	✓	✓	✓	✓
(Felfernig et al., 2000)	✓	✓	5	✓			✓		✓	✓	✓
(Nagel et al., 2011)	✓	✓	3	✓				✓	✓		✓
(Mortensen et al., 2008)	✓	✓	5	✓			✓	✓	✓	✓	✓
(Dahmus et al., 2001)	✓	✓	1							✓	
(Chao and Chen, 2001)	✓		5			✓	✓				✓
(Magro and Torasso, 2003)		✓	5	✓					✓		✓
(Tseng, H.E. et al., 2005)	✓	✓	5	✓	✓		✓		✓		✓
(Jinsong et al., 2005)	✓	✓	5	✓	✓		✓		✓		✓
(Yang et al., 2009)	✓		5		✓		✓				✓
(Zhang et al., 1996)	✓		2		✓		✓		✓		✓
(Zhang et al., 2013)	✓		5		✓		✓	✓	✓		✓
(Mailharro, 1998)	✓		5		✓		✓		✓		✓
(Stumptner et al., 1998)	✓		5		✓		✓		✓		✓

	Product architecture representation			Modelling tool aspects		Modelling focus		Case Study		Target Group	
Contribution	Conceptual	Visual	Level of Formalization	Methods	Computer support	Validation and diagnosis	Products	Process	Industrial application	Domain Experts	Configuration group
(Felfernig and Science, 2007)	✓		4		✓		✓		✓		✓
(Hvam and Ladeby, 2007)	✓	✓	5	✓			✓		✓	✓	
(Haug et al., 2010)	✓	✓	5	✓			✓		✓	✓	
(Erens and Verhulst, 1997)	✓	✓	0	✓		✓	✓	✓			✓
(Felfernig et al., 2004)	✓		5		✓	✓	✓		✓		✓
(Felfernig et al., 2013)	✓		5		✓	✓	✓		✓		✓
(McGuinness and Wright, 1998)	✓		5		✓	✓	✓				✓

3.7.1 Documentation, maintenance, and communication in PCS projects

One of the main challenges when using PCS can be a lack of documentation, which can lead to incomplete and outdated systems that are difficult to understand (Tiihonen et al., 2013). For a company using a PCS, it is therefore crucial to have an efficient system for documenting the structure, attributes and constraints modelled within the system, as well as to facilitate communication between PCS developers and domain experts. Documentation is a vital part of all IT projects, as it is used for sharing knowledge between people and reducing knowledge loss, when team members become inaccessible (Paetsch et al., 2003). The documentation of PCS includes modelling, maintaining and updating the product model, and storing all information related to the products' attributes, constraints and rules inside the PCS (Hvam et al., 2008). Product modelling is a method of representing the structure and knowledge of the product on a relatively visual, abstract level to ensure that they are understandable to all persons concerned.

Four basic representations for modelling product families for PCS are shown in Figure 3-2 (Duffy and Andreasen, 1995). The real world is the product knowledge available at a company. A product model presents product knowledge in a structured way, whereas an information model (IT model) is a formal, IT-based representation of a product model, which is usually based on Unified Modelling Language (UML) notation (Kruchten and Royce, 1996). As an IT model often cannot be understood by most domain experts – especially when it includes complex constraints and rules – the product (or phenomenon) model enables domain experts and configuration engineers to communicate in a common language, thus facilitating future updating and documentation changes (Hvam et al., 2008).

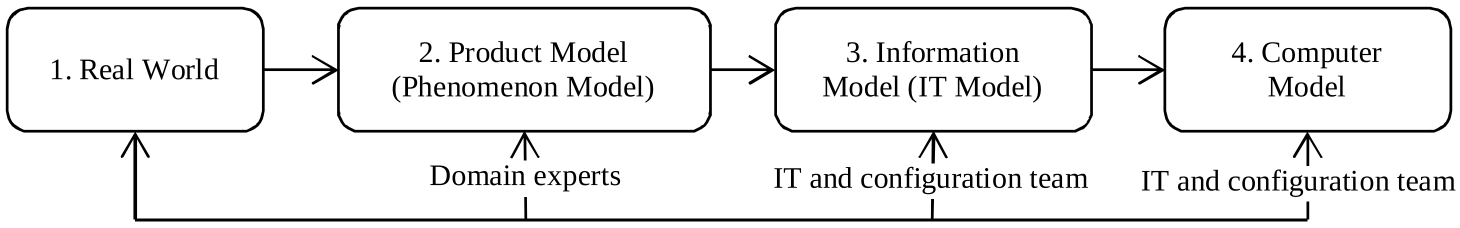


Figure 3-2 Four basic representations of product modelling for PCS (Duffy and Andreasen, 1995).

Previous studies discuss different ways of documenting PCS, which are expressed as product modelling techniques (Haug and Hvam, 2007; Hvam et al., 2008; Jinsong et al., 2005; Yang et al., 2009). There are IT tools available to facilitate the documentation process (Haug, 2009). However, drawbacks to these techniques have been reported as they require manual work to be undertaken, even when IT tools are being used. That is, both the modelling and knowledge modifications have to be maintained separately in the PCS and in the system used for documentation. Accordingly, the knowledge is duplicated, as the knowledge has to be maintained within two separated systems (Shafiee, 2015). Thus, maintenance of the PCS requires updates to be made to the PCS (IT model) and the product model, using both time and resources. Moreover, there is a high risk of the documentation of the configuration models being of low quality (Tiihonen et al., 2013). Rask (1998) addresses documentation and maintenance requirements by emphasising the importance of traceability, verification and versioning. Application of the Dependency Structure Matrix (DSM) method could provide natural and transparent documentation of the ‘knowledge base’ (Sunnersjö et al., 2006). A functionality analysis for Product Model Manager was compared with types of software commonly applied for documenting PCS (Haug, 2009), which showed that the new software offered successful PCS documentation, although the common challenge of additional manual work being required remained. As such, there is still a critical need in the industry for an efficient automatic solution to be found for documenting the knowledge of PCS, communicating with domain experts and validating product knowledge.

3.8 PCS project and integrations with other IT systems

There are a number of research that have explored the hypothesis “the higher the degree of integration across the supply chain, the better a firm performs” (Frohlich and Westbrook, 2001; Hines et al., 1998; Johnston and Lawrence, 1988; Lee et al., 1997; Metters, 1997; Stevens, 1989). Ragatz et al. (1997) identify the linked information systems applicability as a key success factor for integrating suppliers into the new product, process or service development process. Tallon et al. (Tallon and Kraemer, 1996) point out that any positive impact of IT comes from its ability to coordinate value adding activities. A linkage between integrative IT and supply chain is a key aspect of supply chain integration. Stroeken (2001) examines the link between IT and supply chain innovation in six industry sectors in order to show the importance of IT to develop the process oriented structure of the supply chain needed for the integration (Stroeken, 2001).

Mukhopadhyay and Kekre (Mukhopadhyay and Kekre, 2002) quantify both strategical and operational impacts for Electronic Integration which leads to efficient procurement processes. The strategic benefits concerning the supplier and the operational benefits are in respect to both parties, or the suppliers and the customers. It should though be noted that the operational benefits are generated by Electronic Data Interchange (EDI) through reengineering of the internal processes of an organization, unlike strategic benefits, which result from changes in the buyer-supplier trading relationship (Mukhopadhyay and Kekre, 2002). A supply chain strategy recognizes that integrated business processes create value for the companies' customers if these processes reach beyond the boundaries of the firm by drawing suppliers and customers into the value creation process (Stevens, 1989; Tan et al., 1998). Vickery at al. (2003) explain this linkage as the relationship between where one value activity is performed and the cost or performance of another is then introduced as the core purpose of supply chain integration as optimizing linkages amongst value activities.

Inakoshi et al. (1998) propose a framework for PCS that integrates a constraint satisfaction problem with a Case-based Reasoning tool (CBR), where the framework is applied to an on-line sales system. This framework contains the following steps:

1. Case retrieval: similar cases are retrieved from the case base in accordance with the similarities between the current query and the cases.
2. Requirement formalization: a well-defined requirement consists of the current query and the object function, and it is supplied to a Constraint Satisfaction Problem (CSP) solver.
3. Requirement modification: The well-defined requirement is modified only if there is no PCS on and the CSP solver returns no solution back to the CBR Wrapper.
4. Parts database: a parts database that contains the definition of a product family. It defines the types of parts, the constraints on parts connectivity, and other kinds of restrictions on the products.
5. CSP solver: The CSP solver receives a well-defined user requirement and solves the problem.

Based on the current literature in the field, the research highlights the importance of achieving greater integrations in the supply chain where IT plays a significant role. Furthermore, for companies providing customized products, there is a need for having up-to-date information across the supply chains. Therefore, by integrating PCS across the supply chains, it allows companies to further integrate the flow of information and at the same time solve some of the main challenges concerned with MC and PCS. However, the impact from increased integration across the supply chains by enabling interactions of PCSs across the supply chains has not been addressed in the literature.

3.9 Chapter summary

This chapter presented an overview of the available knowledge on PCS projects different phases in general. In the first section, differences and similarities between IT projects and PCS projects was discussed briefly. The conclusion is that PCS projects are special type of IT projects but the available frameworks for IT projects cannot be applicable for PCS projects. However, IT and PCS projects are similar enough that we can use some of the methods and tools or inspired by the available literature for IT projects. Eventually, different phases of PCS projects and available literature is discussed throughout the chapter including: the initiation phase and identifying strategies, benefits and BCs, scoping PCS projects, knowledge management and the knowledge complexity challenges for PCS projects, Modelling and documenting the knowledge, and integration of PCS projects with other IT systems such as ERP system.

In the next chapter, the results from research is presented in the form of 11 papers.

4 RESEARCH SUMMARY

The results from previous chapters clarifies the importance of PCS in ETO companies in terms of the process automation and the products customization. The benefits from PCS are reported in numerous studies. The investigations from literature aligned with the empirical cases gives us a comprehensive understanding of the corresponding objects. PCS have been used in industry over a decade where the literature reports several challenges. Based on those challenges and the gap in the current literature, the RQs in this project are defined. The research objectives of this PhD is to frame and improve the management process of PCS projects: planning, development, and maintenance phases. This objective is broken down into the following RQs: 1) Planning the PCS project, Strategies, motivations, benefits and challenges in PCS management which result in a structured Business case, 2) Scoping PCS project, 3) Managing knowledge across PCS project, 4) Modelling, documentation and maintenance of the PCS projects, 5) PCS integrations with other IT systems. The thesis consists of 24 papers and 11 of them has been considered to answer the RQs. Section 4.1 presents the summary of the selected articles in order to reply the RQs. The RQs are summarized below:

RQ1. How can PCS projects be planned?

> *RQ.1.1. How can we make a strategy to demonstrate different application of PCS projects?*
> *RQ.1.2. How can the benefits and challenges from different PCS projects be evaluated?*
> *RQ.1.3. How can a standard business case for PCS projects be framed?*

RQ.2. How can PCS projects be scoped?

RQ.3 How can we acquire and manage knowledge needed for PCS projects?

RQ.4. How can the PCS projects be modelled and documented?

RQ.4.1. How can we automate the documentation, validation and communication process in PCS projects?
RQ.4.2. How important is it to use the structured modelling and documentation techniques in PCS projects?

RQ.5. How can the integrations with other IT systems lead to improvements in the performance of PCSs?

4.1 Publications overview

In this chapter, an overview of the achieved results from different publications during the three years is presented. As shown in Table 2-2, this PhD study ended up with 24 papers, with a total 15 conference papers and 9 journal papers. The same color-coding in Chapter 1 and 2 is utilized to emphasize on the RQs. All the conference papers are pre-reviewed and published in scholarly conference proceedings between 2014 and 2017. Of the 24 papers, 2 of the journal papers are published, 2 of them are under revision and the 5 of them are submitted.

The PhD thesis is limited to consider the main publications to answer the RQs due to the high number of publications. The other reason for not considering some of the publications in the result chapter is that some of the conference papers presented as the first version in the conferences and then the extended version has been published in the form of journal paper. Furthermore, 11 articles are chosen for result chapter which include 9 journal publications (Table 4-1).

Papers A to E answers to *RQ.1*. Paper A frames a strategy for different applications of PCS for *RQ.1.1.* Papers B, C and D discuss the challenges, benefits and motivations from PCS projects throughout different phases and refer to *RQ.1.2*. Paper E answers the *RQ.1.3* in order to frame a structured BC for PCS projects. Papers E builds on the results from Papers A to D where the structure of BCs is formed based on all the data from ROI to risks and challenges.

Paper F propose a framework to scope PCS projects in the planning phase by using the outputs from BC (Paper E). This paper contributes to fill the gap in *RQ.2.*

Paper G uses the results from Paper F to scope PCS in order to determine the required knowledge in a structured way. The proposed framework for KM is an answer to *RQ.3.*

RQ.4 is answered by Papers H and I. Paper H answers the *RQ.4.1* regarding the need for an automated documentation system by suggesting the agile framework for documentation and communication purpose in PCS projects. Paper H demonstrates the development of IT tool based on the proposed framework in a case company and reports the results. Paper I is a survey paper and evaluate the impact and importance of using a structured modelling technique in PCS projects in order to provide the answer to *RQ.4.2.*

Papers J and K answer the *RQ.5* which evaluates the influence of IT integration with PCS accross supply chain. Paper J propose a framework to assess the similarities between previously designed products in the configuration process. Paper J proves the application of the proposed framework by testing it through an IT tool in a case company. Paper K demonstrates the importance of PCS integration in an external setting in order to obtain accurate information in PCS. The paper discusses a case company that benefits from integrating their own PCS to a vendors PCS.

Table 4-1 Overview of publications

1	RQ.1	A* (Journal)	Kristjansdottir, K., Shafiee, S., Hvam, L., (2017). How to Identify Possible Applications of Product Configuration Systems in Engineer-to-Order Companies. Journal of Industrial Engineering and Management, V. 8, No.3.
2	RQ.1	B (Journal)	Kristjansdottir, K., Shafiee, S., Hvam, L., Myrodia, Anna & Bonev, M. (2017). Economic Value Creation from Using Product Configuration Systems – A Case Study. Submitted Journal article.
3	RQ.1	C (Conference)	Kristjansdottir, K., Shafiee, S., & Hvam, L. (2016). Industrial application of configurators: From motivations to realized benefits. *18th International Conference on Industrial Engineering,* Seoul, Korea.
4	RQ.1	D (Journal)	Kristjansdottir, K., Shafiee, S., Hvam, L, and Forza, C. (2017). The main challenges for manufacturing companies in implementing and utilizing configurators. Submitted Journal article.
5	RQ.1	E (Journal)	Shafiee, S., Kristjansdottir, K., & Hvam, L. (2017). How to frame business Cases Framework for Product Configuration system Projects. Submitted Journal article.
6	RQ.2	F* (Journal)	Shafiee, S., Hvam, L., & Bonev, M. (2014). Scoping a Product Configuration Project for Engineer-to-Order Companies. International Journal of Industrial Engineering and Management, 207-220.
7	RQ.3	G (Journal)	Shafiee, S., Kristjansdottir, K., & Hvam, L., Forza, C. (2017). How to scope configuration projects and manage the knowledge they require. In the second round of revision in International Journal of Knowledge Management.
8	RQ.4	H* (Journal)	Shafiee, S., Hvam, L., Haug, A., Dam, M., Kristjansdottir, K. (2017), The documentation of product configuration systems: A framework and an IT solution. Journal of Advanced Engineering Informatics, doi:10.1016/j.aei.2017.02.004, V.23, pp. 163–175.
9	RQ.4	I (Journal)	Hvam, L.; Kristjansdottir, K.; Shafiee, S.; Mortensen, N.H. (2017), Product configurators: A study of the impact of applying IT formal product modelling techniques. In the third round of revision in International Journal of Production Research.
10	RQ.5	J* (Journal)	Shafiee, S., Kristjansdottir, K. & Hvam, L., (2017). Automatic Identification of Similarities across Products to Improve the Configuration Process in ETO Companies. International Journal of Industrial Engineering and Management, V. 8, No.3.
11	RQ.5	K (Conference)	Kristjansdottir, K., Shafiee, S., Bonev, M., Hvam, L., Bennick, M.H., & Andersen, C.S., (2016). Improved Performance and Quality of Configurators by Receiving Real-Time Information from Suppliers, *Configuration Workshop,* Toulouse, France.

4.2 Planning product configuration systems

This section investigates the possibilities of assessments from the Section 3.2, 3.3, 3.4 that explained the benefits and challenges reported as well as the importance of strategies and BCs in PCS projects. Therefore, the research discusses the strategies, benefits and challenges in PCS projects and introduces the solutions for strategic decisions and benefits quantifications. A BC framework is proposed by the results from previous studies regarding benefits and challenges. This section aims to answer the RQ 1.

4.2.1 Paper A: How to Identify Possible Applications of Product Configuration Systems in Engineer-to-Order Companies

Authors: Katrin Kristjansdottir, Sara Shafiee, Lars Hvam

Published in: Journal of Industrial Engineering and Management, V. 8, No.3., earlier version originally published in: Proceedings of IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Bali, Indonesia, 2016.

4.2.1.1 Research objective and research question

The current literature describes different development strategies that can be applied to companies that use PCSs (Felfernig et al., 2001; Forza and Salvador, 2007a; Haug et al., 2012a; Hvam et al., 2008). However, the literature does not explain how to develop a strategy to guide the development and implementation processes. This includes identifying different applications of PCSs with the aim of getting the most out of the investment by avoiding the sub-optimization of individual processes. Furthermore, stakeholders are more likely to have a common understanding of the overall aim when a strategy is guiding the process. This paper aims to contribute to the literature and help practitioners by providing a framework that ETO companies can use to maximize the value of PCS and minimize risk. This research therefore aims to answer to the following RQ:

How can ETO companies identify possible applications of PCS?

To answers these RQ, a framework is proposed that aims to provide a structured approach to developing a strategy to guide the development and implementation processes of PCSs in ETO companies. The proposed framework is built on the literature in the field of PCSs and was validated through a case study in a real ETO company.

4.2.1.2 Research contribution

In order to guide the development and implementation strategies of PCS in ETO companies, this research proposes a framework that demonstrates alternative ways to apply the PCSs. The following steps must be taken into account when making a development and implementation strategy for PCSs in ETO companies (Figure 4-1):

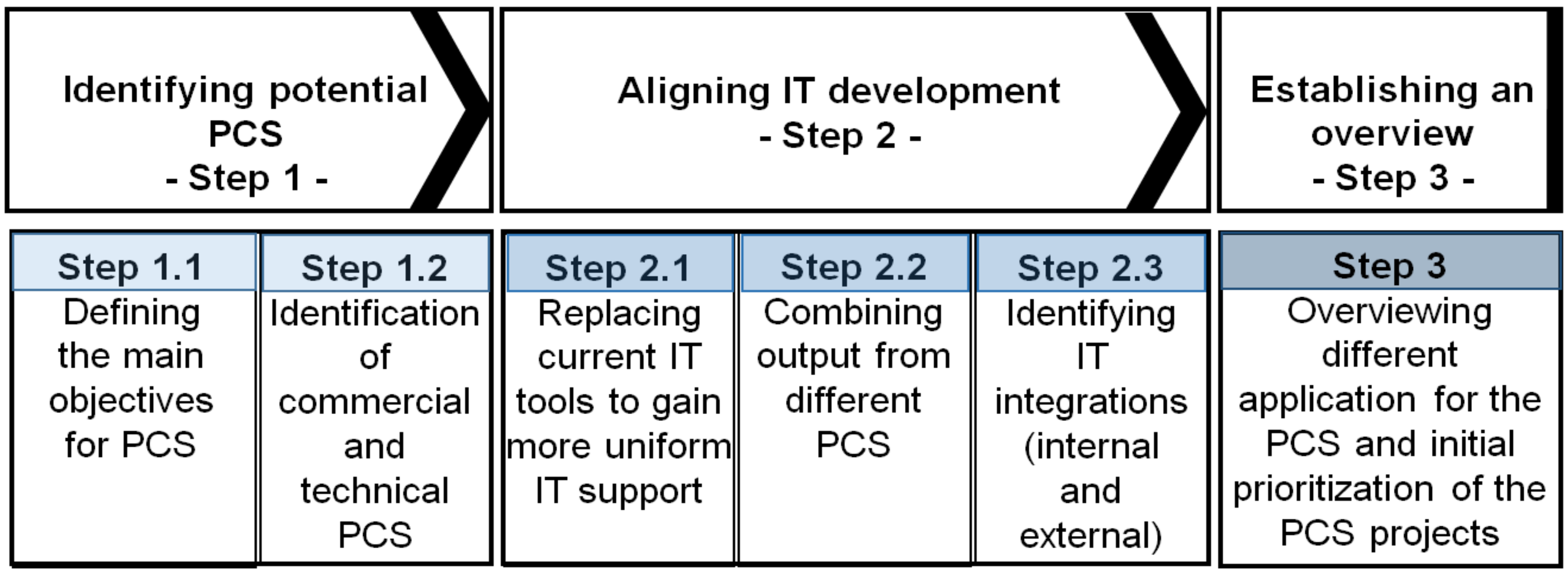


Figure 4-1 The proposed framework to identify applications of PCS.

Case study

The company's main objectives are reducing routine work, decreasing the lead time to generate proposals and product specifications, increasing the hit rate as a result of shorter lead times and improving the quality and ability of the global sales offices to generate proposals. The importance of these objectives can differ from project to project. For instance, for a processing plant with a very low sales rate, the objective of investing in a configurator is to empower all the regional offices around the world and extract implicit knowledge from employees in order to make the information more explicit. In this step, a complete overview was provided to the stakeholders in order show them why the configurators were necessary to achieve these objectives.

The company previously focused on developing configurators that could support the sales processes in the different business units. However, given the increased maturity of the configuration area at the company, an investigation was initiated on how the engineering processes could be supported. Sales and technical configurators are not mutually exclusive. They may even be used in conjunction with each other (see Figure 4-2) where the output of the sales configurator is used as the input for the technical configurator.

This implies a more standardized way of applying the tools and software that are needed to generate different product specifications. In the case study, Excel-based in-house tools were replaced with configurators. This also allowed for more uniform product specifications that are expected to improve the overall quality. Using the same tools also helped.

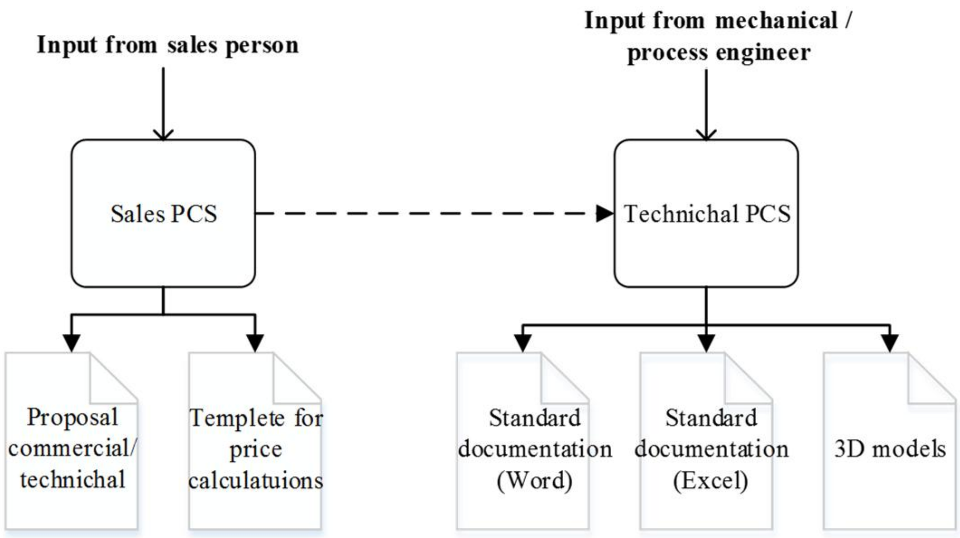


Figure 4-2 The interaction between sales and technical product configuration systems (PCS).

Having an increased number of configurators in operation in different departments opens up the possibility to base the output on the input from individual configurators in order to cover complete projects and plants (see Figure 4-3). With this setup, the sales department could generate proposals by taking input directly from the relevant departments instead of receiving the input via e-mail and copying and pasting it into a Word file. This implies a more standardized procedure across departments and a more structured approach for knowledge sharing.

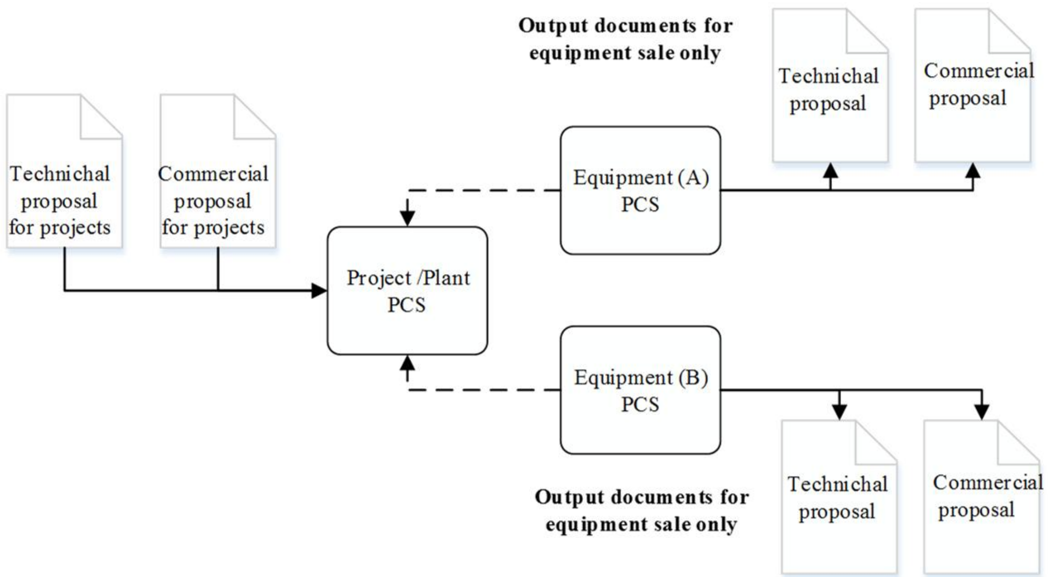


Figure 4-3 Achieving synergy by generating documents using information from product configuration systems (PCS) across departments.

The company in the case study used several software applications for complex calculations and simulations. These software applications provided critical information in the sales and engineering processes.

In order to support a business to the greatest extent possible via configurator development and implementation, it is necessary to obtain a holistic view of each BU. Therefore, visualizations of how configurators can support the different BUs were generated, taking into account the above-mentioned focus areas. Figure 4-4 provides an example of one of the BUs where different development concepts were applied.

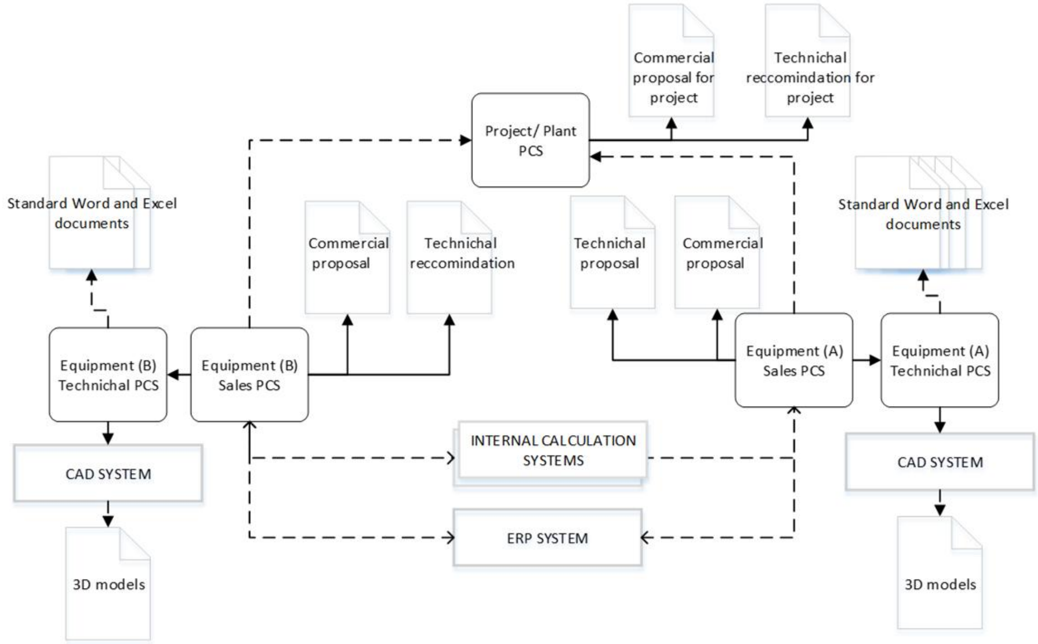


Figure 4-4 Simplified overview how the sales and engineering processes could be supported by product configuration systems (PCS) and interaction with other IT systems.

4.2.1.3 Conclusion

PCSs are usually implemented gradually in ETO companies due to highly complex products and processes, which highlights the importance of having a strategy to guide the development and implementation processes. The literature describes different development strategies (Felfernig et al., 2001; Forza and Salvador, 2007a; Haug et al., 2012a; Hvam et al., 2008); however, none of them specifies how to create a strategy to guide the development and implementation processes for PCS. This is especially important in ETO companies where projects typically have high product complexity that requires the gradual implementation of PCSs. Therefore, this paper aims to fill an important gap in the literature, as well as provide ETO companies with a framework that can help create a more structured approach to development and the implementation of PCSs in order to maximize their investment and minimize risk. Furthermore, this should help companies with strategic planning and when justifying their investments in PCSs, as they can demonstrate the different application areas. Finally, the required resources, benefits and outputs are determined and the requirements are expressed before starting the actual development of the PCS. This study is limited to ETO companies because development and implementation in these companies are more complex. Furthermore, PCS are usually implemented gradually, which highlights the importance of having a strategy. Therefore, future studies should include testing on other kinds of companies, as well as other ETO companies.

4.2.2 Paper B: Economic Value Creation from Using Product Configuration Systems – A Case Study

Authors: Katrin Kristjansdottir, Sara Shafiee, Lars Hvam, Anna Myrodia, Martin Bonev

Published in: Submitted Journal article, earlier version originally published in: Proceedings of 7th International Conference on mass Customization and Personalization in Central Europe (MCP-CE 2016). University of Novi Sad, 2014.

4.2.2.1 Research objective and research question

The gap in the literature regarding the Return On Investment (ROI) for PCSs in companies is not due to a lack of interest, but to challenges related to accessing the necessary data. Such challenges include (1) confidentiality, (2) a lack of availability, and (3) the need for data to be gathered from internal systems at the company and be validated by different stakeholders. This article aims to capture this research opportunity by quantifying the long-term cost savings from using PCSs and compare it to the cost of development, implementation and maintenance of the system. The ROIs at one year and five years are presented. The cost savings factors are calculated based on factors related to resource consumption (man-hours), lead time, the quality of products' specifications and increased sales. These are common benefits of implementing PCSs and are thought to be directly linked to actual cost savings. For this purpose, the following RQ is formulated:

What is the realized ROI for the case company's PCS over a five-year period?

4.2.2.2 Research contribution

To answer the research questions, we first determined whether prior research had quantified the benefits and costs of PCS and, more specifically, whether the expected ROI of PCS is quantified. Next, an in-depth case study was conducted in order to quantify the benefits that are directly linked to cost savings and the overall cost over a five-year period, which were used to calculate the ROI. The results presented in the paper not only fill an important gap in the literature but also identify a benchmark of ROI when investing in PCS projects.

The ROI for a PCS was discussed in previous studies (Barker et al. 1989; Fleischanderl et al. 1998; Forza and Salvador 2002b). Unfortunately, the results are not quantified in this research, and therefore the results cannot be directly compared to those of this study. However, Barker et al. (1989) states that a positive ROI can be achieved in the first year, supporting our findings.

Case study

In this study, the significant benefits of implementing and utilising a PCS in a case company are identified. By comparing the direct cost savings due to reduced man-hours to the direct cost of developing, implementing and maintaining the PCS, it can be concluded that the PCS is highly beneficial for the company within the five-year period analysed. The realised ROI for the PCS can be calculated based on the findings. In Table 4-2, the main findings of the case study are summarised, and the ROI is calculated for both one year and five years after implementation.

Table 4-2 ROI from applying PCS over a five-year period

Cost saving and cost factors associated with the PCS	Amount	Unit
Cost savings based on saved hours over five-year period	31,452,606	€
Cost of development, implementation and maintenance over five-year period	2,406,260	€
Total cost savings over five-year period	29,046,260	€
Realised ROI		
ROI (in the first year after implementation)	477.76	%
ROI (five years after implementation; 2009–2013)	1,207.12	%
Other benefits that could not be quantified		
Lead time savings (average)	4.71	Days
Increase in sales output through PCS	467	%

4.2.2.3 Conclusion

The results of the study show that a high ROI (477.76% after first year of implementation and 1,207.12% after five years) can be achieved by investing in a PCS in a manufacturing company. Our results show that the amount of time required to generate quotations can be significantly reduced; 629,052 man-hours (21.41%) were saved due to the implementation and utilization of the PCS over a five-year period. Our results also show that the lead time for generating quotations was reduced from 8.00 days to 3.29 days (41.13%) due to the PCS. The direct cost factors were divided into three groups: cost of development, implementation and maintenance. Development of the PCS was performed over two years and cost 461,760 €, and implementation costs totalled 300,000 €. Over a five-year period, the cost of maintenance was estimated to be 442,000 €.

The motivation of the study was to analyse the realised ROI for a PCS in a manufacturing company over a five-year period. The ROI is calculated based on the actual cost savings, which can be traced to the man-hours saved when generating specifications for the product and the cost of development, implementation and maintenance. This research aims to fill a gap in the literature regarding the ROI of PCSs and the link between the benefits of PCSs and direct cost savings. This gap exists due to difficulties in retrieving data, such as a lack of availability and validation. The findings of this research show that a positive ROI can be achieved within one year after implementation of the PCS. The ROI is 477.76% one year after implementation and 1,207.12% five years after implementation. This indicates that a PCS is highly profitable when implemented to support the specification processes of manufacturing companies. This paper provides empirical evidence based on single case studies, which impose some limitations on the study. The findings are derived from an in-depth analysis at the company, which was based on historical data, interviews and workshops.

4.2.3 Paper C: Industrial application of configurators: From motivations to realized benefits

Authors: Katrin Kristjansdottir, Sara Shafiee, Lars Hvam

Published in: Published in: Proceedings of 18th International Conference on Industrial Engineering, Seoul, Korea.

4.2.3.1 Research objective and research question

The literature describes the various benefits that can be achieved from utilizing PCSs. However, the motivation behind the implementation and how successful companies are in achieving the benefits that can be related to the initial motivations has not been addressed to great extent in the literature. Besides, the majority of the literature describes the motivations and the realized benefits based on single case company, which makes it difficult to generalize. This paper aims to capture that research opportunity by analysing the actual motivations for implementing PCSs and how successful companies are in achieving the benefits in relation with the initial motivations. In addition, the results provide insight in to the main challenges companies face in the process of providing customized products and how those challenges can be addressed by implementation of PCSs. Aligned with the focus of the study the following RQs were developed:

> *What are the main motivations industrial companies considering for implementing PCSs to support their design and specifications processes?*
>
> *How successful are companies in achieving benefits associated with the initial motivations described prior to the implementation of the PCSs?*

The research method adopted in this paper is based on survey followed with interviews with 22 companies, which all provide customized or engineered products and use PCSs to support the generation of the specifications in the sales and design processes. The survey consisted both of open and closed questions, to capture both the qualitative nature of the main motivations and to quantify to what degree companies agree with achieving the main benefits described in the literature. Based on the answers gathered from the companies the motivations were grouped into seven categorizes.

4.2.3.2 Research contribution

Seven main categorize were identified based on the motivations given by the companies. Those categories are 1) general competitiveness (27% of companies), 2) knowledge management (36% of companies), 3) efficiency in the sales and order process (45% of companies), 4) efficiency in the production process (27% of companies), 5) accuracy of the products' specifications (41% of companies), 6) management of products variants and complexity (23% of companies) and finally 7) other motivations that could not be grouped with the others (24% of companies).

In the first motivation category *general competiveness,* seven benefits were grouped. In this category significant difference of the companies that expressed a motivation in this category can be seen as 79% on average agreed with those benefits while for companies not expressing a motivation grouped into the category 53% agreed.

The second motivation category *knowledge management* three benefits were grouped. However, not significant difference can be found between companies expressing a motivation in this category and the ones not expressing a motivation in this category, as the number of the companies agreeing to the benefits on average are 67% and 66% consequently.

The third motivation category *efficiency in the sales and order processes* four benefits were grouped. However, an interesting finding is that on average 90% of the companies, which did not express a motivation in this category agreed with those benefits while 78% of the companies expressing a motivation in the category agreed on average. Therefore, higher percentages of companies not expressing a motivation grouped in this category agreed with achieving the associated benefits.

The fourth motivation category *efficiency in the production processes* two benefits were grouped, which are (15) reduction of cost in relation with construction and production, and (16) reduction of cost in relation with production and procurement of materials. Out of those two benefits 77% of the companies agreed with reduction of cost in relation with construction and production being a benefit while 46% of the companies agreed with reduction of cost in relation with production and procurement of materials. In terms of companies that expressed a motivation grouped into this category a significant different was found. On average from the companies expressing a challenge in this category 83% agreed with this being a realized benefit, while only 53% of companies not expressing a motivation in the category agreed on average with this benefit.

The fifth motivation category *accuracy of the products' specifications* three benefits were grouped. In terms of companies that expressed a motivation grouped into this category a significant different was found as 71% on average agreed that those three benefits were realized from using the system while 64% of companies not expressing a motivation in the category agreed on average.

The sixth motivation category *management of products variants and complexity* three benefits were grouped. An interesting finding is that on average 70% of the companies, which did not express a motivation in this category agreed with those benefits while only 50% of the companies expressing a motivation in the category agreed on average. Therefore, higher percentages of companies not expressing a motivation grouped in the category agreed with achieving the associated benefits.

4.2.3.3 Conclusion

The *first RQ* aims to identify the main motivations for the implementation of the PCSs. The main motivations were grouped into seven categories, which are to 1) improve general competitiveness, 2) knowledge management, 3) efficiency in the sales and order processes, 4) efficiency in the production processes, 5) accuracy of the products' specifications, 6) management of products variants and complexity and finally 7) other motivations. *The second RQ* aimed to express how successful companies were in achieving the benefits associated with the motivations prior to the implementation. For the motivation categorizes, general competiveness, efficiency in the production process and accuracy of the products' specifications, companies that expressed a motivation grouped into these categories agreed to greater extent with the associated benefits being realized in their companies. That means that companies that have plans from the beginning to achieve those goals are more likely to accomplish them. For the motivation categories efficiency in the sales and order processes and management or product variants the companies that expressed a motivation grouped in to these categories, agreed to less extent than the companies not expressing a motivation into the category that this was a realized benefit. Finally, for the motivation category known as knowledge management now significant difference could be determined between the companies expressing a motivation in the category and not in terms of the to what degree companies agreed of the associated benefits being realized benefits associated with the usage of the PCSs.

4.2.4 Paper D: The main challenges for manufacturing companies in implementing and utilizing configurators

Authors: Katrin Kristjansdottir, Sara Shafiee, Lars Hvam, Cipriano Forza

Published in: Submitted Journal article.

4.2.4.1 Research objective and research question

The challenges relating to PCSs that have been discussed in the literature are mostly based on single case studies, and the importance of the challenges is not usually assessed in terms of the overall project's success. It is therefore difficult to generalize the main challenges manufacturing companies face when implementing and utilizing their PCSs or the importance of the individual challenges on the success of the PCSs. This research study aims to capture this research opportunity. Therefore, this paper first identifies and categorizes the main challenges manufacturing companies face when implementing and utilizing their PCSs, and then assesses the importance of those categories, highlighting the specific challenges that can be found within each category. This research therefore aims to answer to the following RQs:

What are the main categories of challenges that manufacturing companies face when implementing and utilizing the PCSs?

What is the importance of each category of challenges that companies face when implementing and utilizing their PCSs?

Which specific challenges within each category do manufacturing companies face when implementing and utilizing the PCSs?

To answer the RQs, a literature study and survey comprising open and closed questions was adopted as the research method in 22 companies. The open questions were used for RQs 1 and 3, to identify additional categories of challenges that are not described in the literature and to identify the specific challenges belonging to each of those categories. The closed questions were used for RQ 2, which asked respondents to rate the importance of six categories of challenges identified in the literature on a five-point scale.

4.2.4.2 Research contribution

Based on the first RQ, six main categories were identified from the literature review: challenges related to IT (technical), product modelling, organisational challenges, resource constraints, product-related challenges, and challenges related to knowledge acquisition. The second RQ was concerned with the importance of the categories representing the main challenges when implementing and utilising PCSs. In terms of importance, IT challenges were the most commonly reported categories of challenges experienced at companies but they were rated as having the lowest importance. Finally, the third RQ aimed to provide more in-depth knowledge about the specific challenges that manufacturing companies face when implementing and utilising their PCSs for each of the categories.

Case Study

The first part of the research explores the main challenges manufacturing companies face when implementing and utilising configurators. The answers provided by the companies are grouped into main categories identified in the literature according to their nature. The results presented in this section are aimed to verify the main categories identified, (2) to ascertain whether additional categories would be found, and finally (3) highlight specific challenges described within each of the categories. In Table 4-3, the percentages of companies expressing a challenge grouped into the different categories of challenges are shown.

Table 4-3 Percentages of companies expressing (one or more) challenges grouped into the categories

Challenges expressed by the companies grouped into certain category	% Companies expressing a challenge
1. IT challenges	36.36%
2. Product modelling	40.91%
3. Organisational	68.18%
4. Resource constraints	22.73%
5.Product-related	22.73%
6. Knowledge acquisition	59.09%

The second part of the research focused on identifying the importance of the challenges experienced when implementing and managing configurators.

Table 4-4 presents the importance of the main categories of challenges that were measured on five-point scale ranging from 1 (not important) to 5 (very high importance). Furthermore, the results are summarised into three groups ranging from not important (1), low importance (2-3) and high importance (4-5).

Table 4-4 The importance of the main categories of challenges

	Quantitative (RQ. 2)				
	Not important	Low		High	
	Not important	*Very Low*	*Low*	*High*	*Very High*
1. IT challenges	9.09%	54.55%		36.36%	
	9.09%	31.82%	22.73%	18.18%	18.18%
2. Product modelling	9.09%	40.91%		50.00%	
	9.08%	22.79%	18.18%	36.36%	13.64%
3. Organisational	13.64%	36.36%		50.00%	
	13.64%	13.64%	22.73%	36.36%	13.64%
4. Resource constraints	18.18%	36.36%		45.45%	
	18.18%	13.64%	22.73%	31.82%	13.64%
5.Product-related	22.73%	50.00%		27.27%	
	22.73%	31.82%	18.18%	18.18%	9.09%
6. Knowledge acquisition	18.18%	31.82%		50.00%	
	18.18%	18.18%	13.64%	36.36%	13.64%

IT (technical) challenges was ranked fourth out of the six in the qualitative part of the study (section 1.3). However, 9.09% of the companies did not consider this an important challenge, 54.55% stated that the challenge has a low impact and 36.36% placed a high level of importance on the challenges faced in this category. Thus, while IT challenges cause problems with implementing the configurators, the majority (54.55%) of the companies considered these problems to be of low importance.

Product modelling challenges were expressed by 40.91% of the companies in the qualitative part of the study, placing it the third most common challenge. As for IT challenges, 9.09% of the companies did not consider these challenges important. However, 50.00% of the companies placed high importance on this category, and 41% of the companies' rated this category with low importance.

Most of the respondents (68.18%) expressed *organisational challenges* in the qualitative part of the study. In the quantitative part of the study, 13.64% of the companies rated this category as not important, while 36.36% considered it to have low importance and 50.00% high importance. Indications were found that when organisational challenges were rated with high importance, other challenges also became more significant, especially challenges related to resources.

In terms of challenges related to *resources constraints,* 22.73% of the companies mentioned these challenges in the qualitative part of the study, making them the least mentioned category along with product-related challenges. However, in the quantitative part of the study, 18.18% of the companies rated these challenges as not important, 36.36% placed low importance on this category and 45.45% considered these challenges highly important. The companies that rated these challenges with high importance also rated organisational challenges with high importance, and a tendency was found for resource constraints to affect the other challenges, thus raising its importance. This indicates that organisational and resources-related challenges have an impact on other challenges. Thus, even though it was not mentioned as one of the main challenges in the qualitative part, this type of challenge has a higher impact as an underlying challenge.

Product-related challenges, which were mentioned by 22.73% of the companies in the qualitative part, were the least mentioned challenges. Aligned with those findings, most companies see this challenge as an unimportant challenge in relation to managing the configurators; 50.00% of the companies rated this as a challenge with low importance and only 27.27% considered it highly important, making this category ranked by fewest companies as important.

Finally, challenges related to *knowledge acquisition* (59.09%) were the second most mentioned in the qualitative part after organisational challenges. Aligned with that, this category was rated with high importance by 50.00% of the companies and low importance by 31.82% of the companies.

4.2.4.3 Conclusion

The empirical findings presented in this study confirm the challenges that have been presented in previous literature and add greater insight. However, the sample of 22 companies used in this research limits the generalisability of the results. Future studies should therefore use a larger sample size. Furthermore, the importance of the different subcategories should be researched further. Nevertheless, the findings are thought to represent some of the challenges manufacturing companies face and provide greater insight into how the companies experience these challenges when implementing and utilising their PCSs. This research study should raise the awareness of other companies regarding the challenges faced when implementing and managing PCSs.

4.2.5 Paper E: How to frame business Cases Framework for Product Configuration system Projects

Authors: Sara Shafiee, Katrin Kristjansdottir, Lars Hvam, Anders Haug

Published in: Submitted Journal article, earlier version originally published in: Proceedings of 7th International Conference on mass Customization and Personalization in Central Europe (MCP-CE 2016). University of Novi Sad, 2014.

4.2.5.1 Research objective and research question

PCS projects are a particularly complex type of IT system (Salvador and Forza, 2004), which can be clarified in terms of (1) a diverse set of process elements (e.g. machines, operations), (2) a high variety of component parts and assemblies, and (3) a large number of constraints and rules (Zhang and Rodrigues, 2010). Some studies have introduced different steps that can be used to define the BCs for PCS, such as stakeholders' analysis and process evaluations (Felfernig, Hotz, et al., 2014). However, existing literature fails to provide a systematic framework to guide the definition of BCs for PCS projects. To address this issue, this paper aims to answer the following research question:

How can we frame business cases to guide PCS projects?

To answer this question, we develop a specific BC framework for PCS projects, which we test in three PCS projects at two engineering companies. The framework aims to help practitioners evaluate their investment in different PCS projects while prioritising and evaluating the projects in terms of the goals, scenarios and cost benefits before the project's initiation.

This study comprises a literature review, framework development and validation. The literature review positions existing research in the scientific discussion to ascertain the need for our research. The *first phase* of the research aims to find a suitable BC foundation from those available for IT projects, and the *second step* investigates the possible differences between IT and PCS projects, which highlight the need for specific BC frameworks for PCS projects. The *third step* discusses the specific requirements and tools for BCs in PCS projects and the lack of suitable frameworks. In the *fourth step,* we consider BC frameworks that have been developed for IT projects in general and ascertain the tools and requirements that are available for PCS projects. After making the final decisions about the sequence of steps and proposed tools for the framework, the *last step* involves conducting multiple case studies to validate the usability of the framework in different circumstances.

4.2.5.2 Research contribution

There are multiple frameworks for BCs for IT projects, in which there are overlaps in the elements included. Some of the authors focus on the steps of BC development at a high level of abstraction (Ashurst et al., 2008), while some are very detailed (McNaughton et al., 2010). Based on the literature, it can be concluded that the main elements for BCs in IT projects can be described in terms of 1) benefit analysis, 2) stakeholder's analysis, 3) IT requirements, and 4) risk and cost analysis. However, as mentioned, these frameworks have limited usefulness to support BC definition in PCS projects because of the differences between general IT projects and PCS projects.

Although the PCS literature does not in a detailed manner deal with the definition of BCs, some of the aspects that involve BCs have been described. *Benefit analysis* is a vital challenge for PCS projects as it determines the requirements of the project and shed light into project scoping (Hvam et al. 2008; Shafiee et al. 2014). *Stakeholders' analysis,* the users' expectations and requirements for the system increases as PCS projects become more successful and popular among users (Barker et al., 1989). *Process analysis* is one of the major steps before initiating PCS projects, where the sales and engineering process are redesigned to increase efficiency by the help of PCSs (Forza and Salvador, 2002b). *Cost and risk analysis* are carried out to compare the different scenarios. In the literature, the cost estimation for evaluating the savings from PCS and further sensitivity analysis has been conducted (Kristjansdottir et al., 2016).

Framework development

The suggested framework sequence in this paper is based on currently available IT frameworks. However, owing to the general similarities and differences between PCS and IT systems, the framework is developed based on different tools and methods available for PCSs' BCs. The framework is improved in an iterative process using a case company while benefiting from the experiences and knowledge of the practitioners and academics.

Based on the discussions in literature, the main BC steps available for IT projects (benefit analysis, stakeholder's analysis, IT requirements, and risk and cost analysis) and tools for PCS projects reveal that it is possible to keep the sequence and core of the framework from IT projects. However, the tools and methods are more specified for PCS projects. Furthermore, based on the literature, PCS projects call for a strong process evaluation and report challenges for more accurate cost analysis. In most of the cases, the IT structure and platform for PCS projects is fixed and decided when the concept of PCS is founded in the company and there is no need to discuss the IT architecture in each BC every time. Hence, based on literature, discussions and initial testing, the IT requirement step is substituted with the process and gap analysis which is also including the IT architecture discussions if necessary. Because of the emphasis on inaccurate cost estimation in PCS projects, sensitivity analysis step is introduced. The main steps decided for BCs framework in PCS projects are:

1. Benefit analysis
2. Stakeholders' analysis
3. Process analysis, scenario making, and gap analysis
4. Scenarios evaluation:
    - Cost-benefit analysis
    - Sensitivity analysis
    - Risk Analysis

Step 1: Benefit analysis

The literature emphasizes on the various benefits gained by using PCSs in different organizational settings. Based on the commonly described benefits, the goals of the implementation have to be aligned with the current strategy and difficulties at the company. Identifying the goals and the desired benefits to be gained from the implementation of the PCS is highly important as it will provide guidelines for the following steps.

Step 2: Stakeholder analysis

For both PCS and IT projects, in general, the categorization of requirements can be divided into two types of requirements: functional and non-functional. Demands for a better communication with stakeholders specifically in PCS projects leads to illustrate requirements through use case diagrams (Shafiee et al., 2014). Furthermore, the requirements have to prioritize based on their importance. The MoSCoW rule can be beneficial when prioritizing the stakeholders' requirements (Bittner, 2002): Must have (Mo), Should have (S), Could have (Co), Want to have (W).

Step 3: Process analysis, scenario making, and gap analysis

The specification process at the company is analysed in order to get an overview of the most important activities, their sequences, and connections, list up the persons responsible for the different activities, information flows and the processes' inputs/outputs. Understanding the current processes is a fundamental step to design how the future processes would look like with the support of PCS.

Step 4: Scenario evaluation

The last step of the framework is concerned with evaluating the proposed scenarios based on (Hvam et al. 2008; Shafiee et al. 2014; Kristjansdottir et al. 2016):

- Cost-benefit analysis
- Sensitivity analysis
- Risk analysis

Based on the discussions about the complexity and unpredicted costs of PCS projects, cost and risk analysis for BC discussed to be a challenge as it is a rough estimation and needs more attention from academia (Shafiee et al., 2014). The financial benefits for PCS projects should be clear from the beginning and cost evaluation is one of the most important purposes of doing BCs. Cost-benefit analysis are carried out to compare the expected costs and benefits for the different scenarios and in general is a financial method to compare different results from a variety of actions (Haddix et al., 2003). Return On Investment (ROI) is commonly used as a cost-benefit ratio, which is a performance measure used to evaluate the efficiency of a number of different investment (Phillips and Phillips, 2010) and it has been used in PCS projects to determine the profitability of these projects.

In order to take the uncertainty or changes in different parameters into the account and increase the accuracy of the cost analysis, sensitivity analysis is conducted. Sensitivity analysis is concerned with representing the certainty which can be apportioned to different sources of uncertainty in its output (Saltelli, 2002).

Case studies

The proposed framework for BCs of PCS projects was tested in two engineering companies. Workshops were conducted to introduce the proposed framework and the tools suggested in the individual steps to all the stakeholders. Finally, feedback meetings were held as semi-structured interviews to collect knowledge about the team's satisfaction with the new framework. The interview questions aim to obtain a general evaluation of the benefits and challenges associated with the framework's performance.

Benefit analysis

The goals of the project should reflect the benefits of implementing the PCS from the stakeholders' viewpoint. The main benefits identified in this step are concerned with reducing the time needed for meetings with experts and to clear the task assignment before further decisions are made. The determined goals differ for the companies because they reflect the companies' current operational challenges.

Stakeholders' analysis

The benefits of using these methods are (1) a full understanding of stakeholders' requirements and (2) improved communication and task delegation, which results in saving resources and time. The stakeholders reported the main obstacle in this step as the unfamiliarity with the introduced tools. lists the main results from the cases in this phase.

Process analysis

A common understanding of the current processes provided learning points for the stakeholders. In all cases, the numbers of redesign loops were noticed due to an insufficient flow of information in the various steps of the processes. Furthermore, the gap analysis provided an effective overview of the future state at the companies. Training sessions were prepared to ensure employees knew how to use the new methods; however, stakeholders considered this a time-consuming process. The gap analysis also helps to communicate the need for implementing the PCSs in all cases and thereby increases the stakeholders' commitment to the project.

For Case 1, the expected time savings created by automating the process will not cover the cost of man-hours saved because the quantity of plants sold every year is too low. Therefore, the savings are calculated based on selling one more plant per year. However, Cases 2 and 3 will save on man-hours because of the higher quantity of products or processes sold each year. The cost is calculated as the project cost, which includes the development and implementation and the yearly running cost, such as licenses and maintenance activities. The risk of system avoidance from users highlighted the need for good management to change employees' mind-sets. The solution was to involve all future system users from the beginning of the project to create a feeling of ownership and commitment. Another risk relates to the benefit realization of the project and trust in the accuracy and stability of the calculations. The solution was to present visualizations of all the data and formulas in the system to the domain experts and to involve them in testing the system.

4.2.5.3 Conclusion

This paper proposed a framework for developing BCs for PCS projects, based on the available literature for IT and PCS projects. The suggested framework and the suggested tools should help the whole team to focus on and prioritise the goals, specific stakeholders' requirements, analysis and design of the current and future processes where PCS is used, and the evaluation of future scenarios based on cost benefit analysis, and sensitivity and risk analysis.

The framework tested in three PCS projects at two engineering companies proved the application of the framework in different projects and in different companies. To validate the framework, we have clarified the application of the framework and the different steps involved. All three projects aimed to reduce the complexity of the current processes and achieve economic benefits from implementing a PCS. The results from testing the framework and observations of the case studies show the interest among the whole team in using suggested BC framework as well as its challenges at the company. It also sheds light on unclear points in early phases of the PCS projects such as the expectation from the system.

4.3 Scoping of product configuration systems

This section investigates the possibilities of assessments of the Section 3.5 that refined the importance of scoping in PCSs. Therefore, this section addresses the scoping of PCSs by introducing a framework. This section aims to answer the RQ 2.

4.3.1 Paper F: Scoping a Product Configuration Project for Engineer-to-Order Companies

Authors: Sara Shafiee, Lars Hvam, Martin Bonev

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4.3.1.1 Research objective and research question

In order to start a PCS project, there is a need for deeper understanding of how to scope these kind of projects. This paper reflects upon the available literature and refines it within the ETO companies and in the context of process plants and machinery applications. The PCS deals with broad range of knowledge and seeks for high level management skills and planning to align different resources with different expertise. The research group experiences reveal the lack of focus on PCS even from the first steps to the final release. This lack of focus and planning leads to both poor performance, increases of time and resources consumption in all phase of the PCSs. Acting upon this challenge, this paper suggests a framework for scoping PCSs in companies with complex and highly engineered products. This framework is based on a general and well-established framework for scoping IT-systems and on specific tools for managing PCSs. The main results will be discussed in the following sub sections.

4.3.1.2 Research contribution

Based on literature in the field of PCS and the based iteratively testing the framework, the following steps are proposed for scoping PCS projects:

1. Aims and purpose for the PCS and overall process flow
2. The identification of stakeholders and their requirements
3. IT-architecture incl. flow in the PCS, UI, input, output, integrations, and the main functionality of the PCS
4. Products and product features to include in the PCS, including level of detail
5. A project plan including resources, time table, modelling approach, test and development, system maintenance, etc.

Aims and purpose for the CS and overall process flow

This part will discuss the overall aim and purpose of implementing PCSs as the vision for specific PCSs projects, which can differ across different projects. However, there are general aims and purposes which are usually the same, even though the importance can vary, which are: lead time and resources reduction, automatic document generation, fewer errors and higher quality, higher independency and empowering sales resources, knowledge management and documentation, standardization and modularization of the product range and etc.

Stakeholders' identification and their requirements

The subsequent steps of the project should be based on the stakeholders' needs. There is a need to analyse the stakeholders in the very first steps of the project to support the prioritization of the individual requirements (Tiihonen et al., 1996a). One of the first method to illustrate the stakeholders' requirements is TO-BE process and the other one for this purpose could be use case diagrams from Rational Unified Process (RUP) method (Kruchten, 2007). Flowcharts demonstrate the workflow and task floating between different stakeholders by the focus on the process. Use case diagrams tools express the requirements and the actors involved in the project, while the same use case can be utilized in system analysis, design, implementation and testing.

IT-architecture

IT architecture addresses the technical aspects and structure of the PCS. there are techniques to handle the product or process models for PCS especially when managing big sized complex projects such as recommendation systems (Tiihonen et al. 2014).

Products and product features

Having a good description of products and process features leads to an efficient level of details in PCS which reflects on some of the technical and business aspects such as: avoiding complexity in PCS, knowledge management and documentation, saving time and resources, efficient communication with domain experts.

Project plan and modelling approaches

The RUP method is a popular iterative software development process which is customizable for specific organizations or projects (Kruchten, 2007). This method and the tools introduced such as modelling tools or component based development can be used for PCS projects (Figure 4-5).

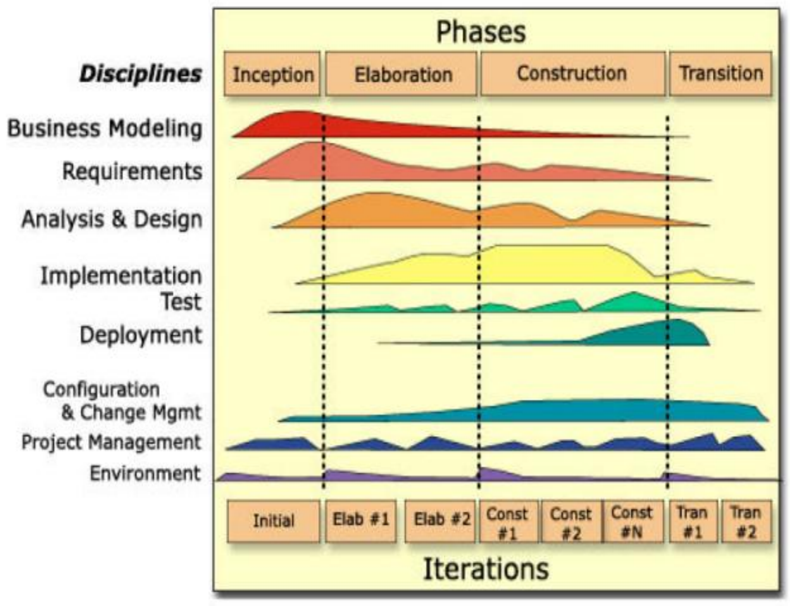

Figure 4-5 Unified Process (Kruchten, 2007)

One of the major steps is to find an efficient structured "*modelling*" tool, such as Product variant master (PVM) (Hvam et al., 2008) in order to understand the product hierarchy and facilitate the communication process. CRC stands for "Class, Responsibility and Collaboration" and these cards are used to define the classes and hierarchy and other detailed information to be added to the PVM (Hvam et al., 2008). *Documentation and maintenance* is highly depending on modelling and the tools used in this step such as PVM. This tools can be used for communication, clarification and documentation and maintenance of the system.

"Component-based development" is about to split the project into smaller components and deliver it in small versions. A component based strategy can be very helpful especially in complicated and highly engineered projects (Felfernig et al. 2014) and help to deliver and test the system iteratively. Method recommended to be used in this step are weighting tables, where each requirement is rated against several specific, weighted project success criteria and a score is computed to rank the priority of the requirements (Wiegers, 1999). *"Testing"* is included in the iteration template, and it is as critical for PCSs as it is for other IT projects. For "*project planning",* it is possible to have two different plans: 1. The first plan is a coarse project plan with start and end dates of all phases and iterations. In Figure 4-6 the general iteration process specifically for PCS projects is illustrated.

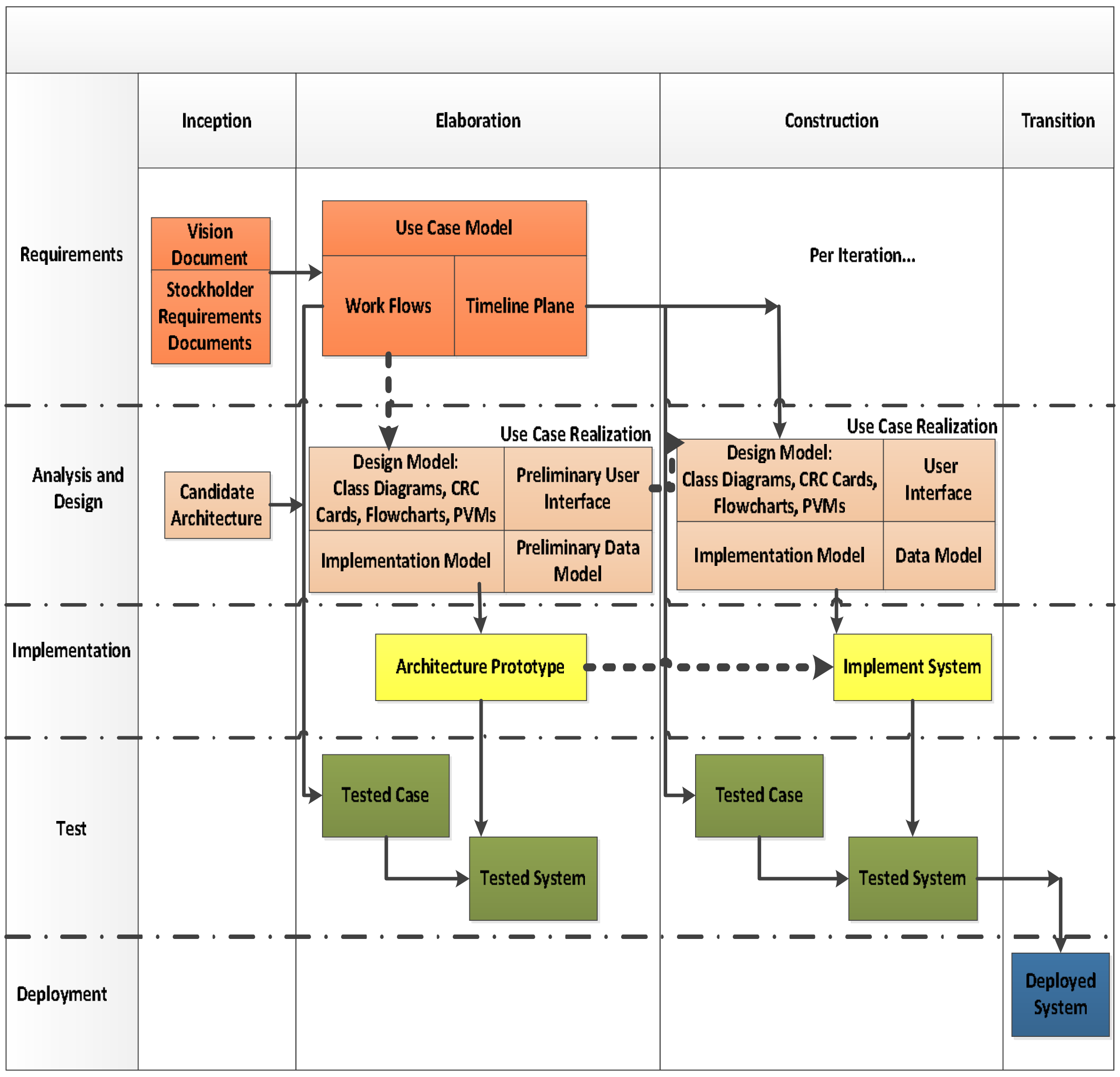

Figure 4-6 The general iteration process template for PCSs

Case study

The framework development is based on literature and iterative testing and experiences from industry where the authors have been involved in more than 20 PCS projects. Thereafter, the proposed framework has been applied in a ETO industry to assess its functionality and possible challenges in a real project from the planning to the release phase. The case company is an international company specialized in the production of heterogeneous catalysts and in the design of process plants based on catalytic processes.

Step 1: Aims and purpose for the PCSs

The main aims of the project define based on the challenges of the selected case (a process chemical plant) regarding complexity, empowering the local offices, knowledge documentation and needed resources. In order to describe future scenarios, it is necessary to have a comprehensive overview of the current situation. Sales persons are currently using excel sheets and a complex homemade calculation system as the main foundation for the creation of technical proposals. Based on the current processes different scenarios were made where the PCS is used, the chosen scenario for the project shown in Figure 4-7.

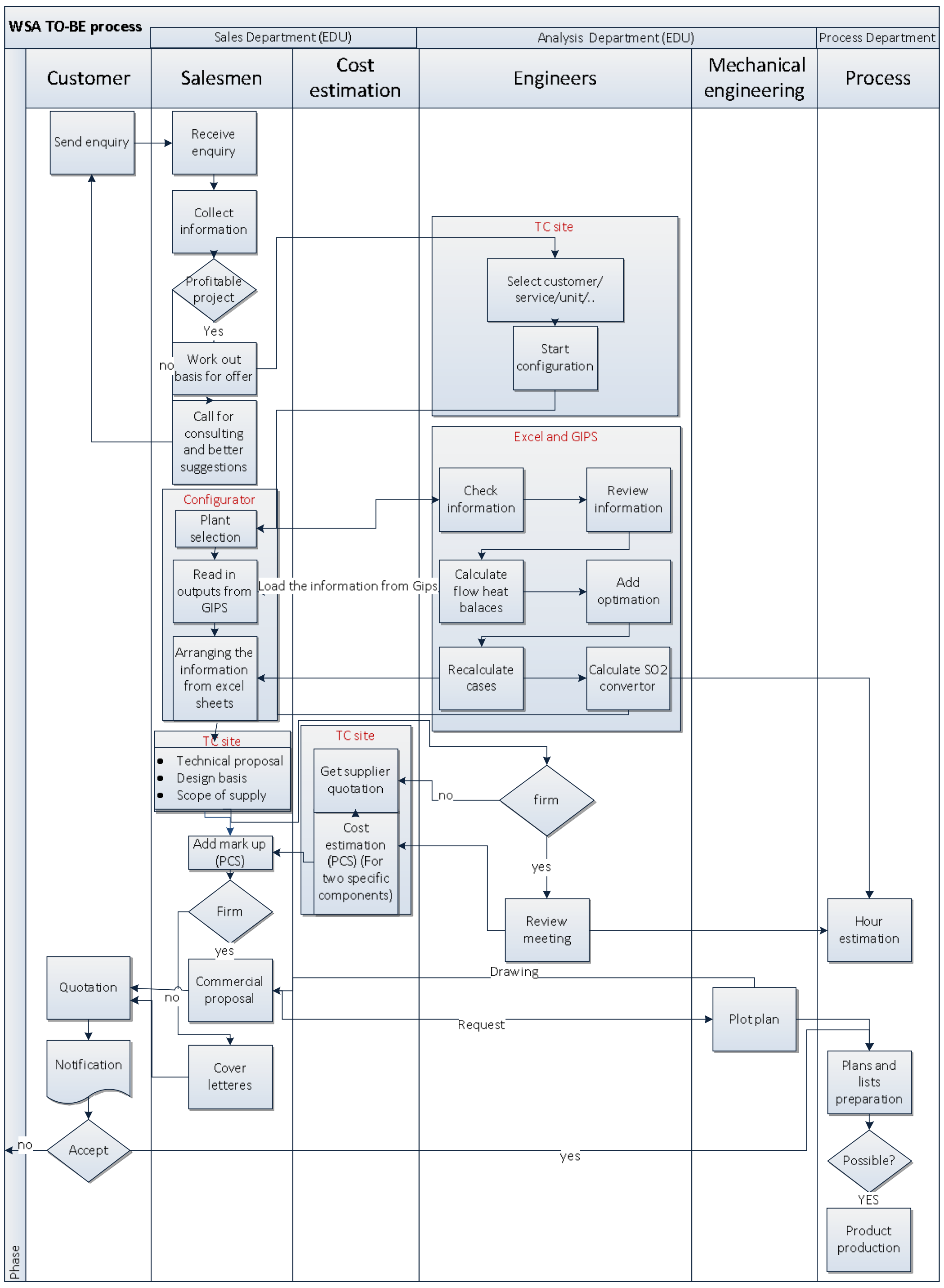

Figure 4-7 TO-BE process example

Step 2: Stakeholders' identification and their requirements

For this specific project, the stakeholders are the sales staff, cost estimators, process and chemical engineers, product developers, marketing staff, regional offices and general managers with different requirements and inputs for the project. Figure 4-8 illustrates an example for use case diagram used in this project to demonstrate the stakeholders requirements.

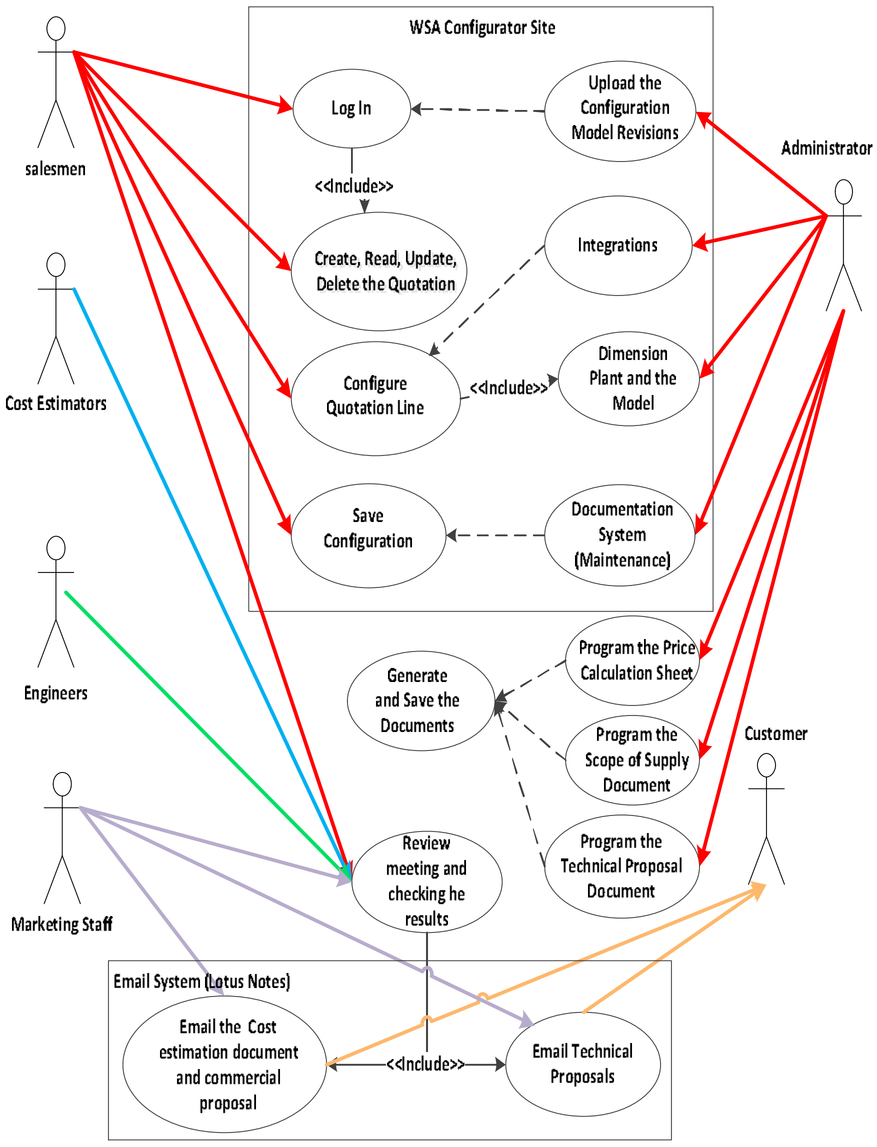

Figure 4-8 Use case diagram example

Step 3: IT-architecture

Examples of the main functionalities of the PCS are: capacity dimensioning of the entire plant, cost estimation for the machineries, calculations of engineering hours, energy consumption and etc. From IT aspects, different plugins and integration to the main calculation and simulation system at the company are required to introduce a fast error-free solution for the stakeholders.

Step 4: Products and product features

Figure 4-9 shows the reverse engineering process used for finding the needed inputs and managing the level of details. As an example, stakeholders asked for price calculation sheets, which are a combination of all component prices according to their internal selections and sizes, the engineering hours based on the plant complexities, consultancy hours, transportation expenses depending on the size and type, insurance and destination.

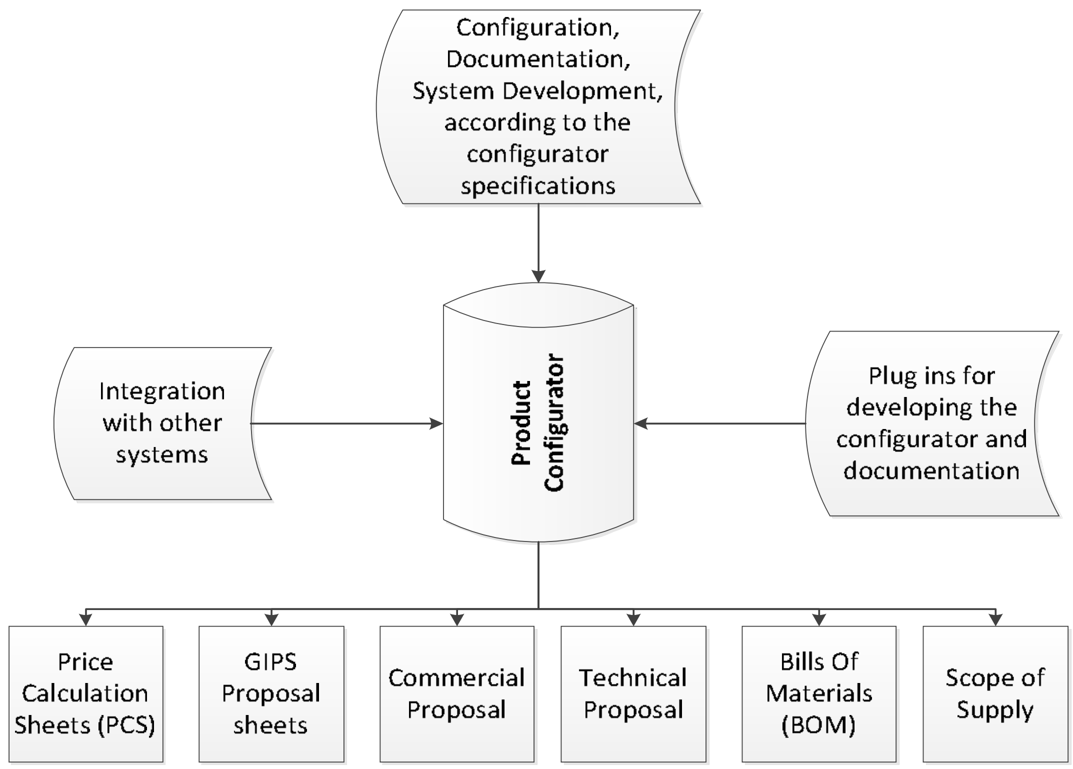

Figure 4-9 The model subject layer and integration with other systems

Project plan and modelling approaches

Concerning the complications in project and the importance of having an up to date PCS, documenting of the system initiated in early phases of the project; while considering PVM as the modelling and documentation tool (Figure 4-10).

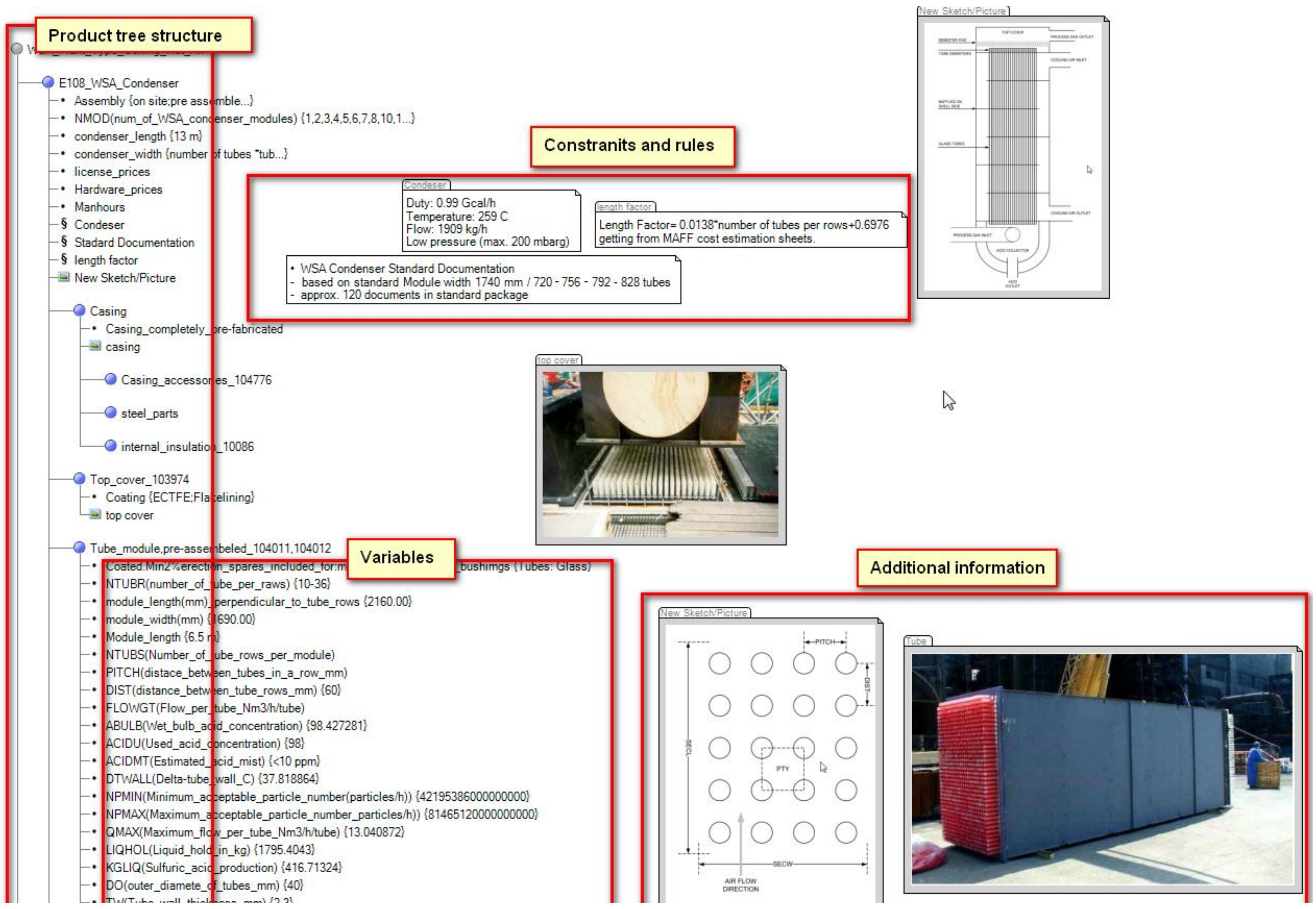

Figure 4-10 The initial PVM structure example

In order to break the project to smaller pieces and to prioritize the products and functionalities to be included in the PCSs, it is recommended to use weighting tables (Wiegers, 1999) as it provides structured approach. In Table 4-5, the calculations of weighting table are assessed using the explanations from Weigers (1999).

Table 4-5 Priority Table example based on Weigers (1999)

Feature	Relative Benefit	Relative Penalty	Total Value	Value %	Relative Cost	Cost %	Relative Risk	Risk %	Priority
Product 1	5	5	15	21.1	2	12.5	5	31.3	0.116
Product 2	9	9	27	38.0	5	31.3	2	12.5	0.209
Product 3	5	2	12	17.0	3	18.7	3	18.7	0.151
Product 4	4	1	9	12.6	4	25	5	31.3	0.049
Product 5	2	4	8	11.3	2	12.5	1	6.25	0.361
Totals	25	21	71	100	16	100	16	100	--

4.3.1.3 Conclusion

This paper clarifies that having a standard framework for implementing PCSs has a remarkable effect on decision making in the early phases of the project. The suggested framework for scoping a PCS has been tested in a case company. In the case company, the framework proved to be useful for the project team in supporting an early clarification of the PCSs. The developed framework formed a solid basis for the subsequent PCSs project and helped to focus and give priority only to needed parts of the PCS. However additional research is required regarding the maintenance and testing stages. The case study moreover revealed some challenges in identifying and prioritizing the stakeholders and their requirements, which is a field that needs more research in the future. Finding a solution for the documentation and maintenance part of the PCS also need further research. Furthermore, the suggested framework needs to be tested in a number of companies to further validate it, and to test if the frame-work could be used also in other kind of companies than only ETO companies with complex and highly engineered products.

4.4 Knowledge management

This section investigates the possibilities of assessments of the Section 3.6 which refined the importance of knowledge management in PCS projects. Therefore, this section addresses the scoping of PCSs in terms of the complexities in determining the needed knowledge, the process of knowledge acquisition, validation and maintenance. This section aims to answer the RQ 3.

4.4.1 Paper G: How to scope configuration projects and manage the knowledge they require

Authors: Sara Shafiee, Katrin Kristjansdottir, Lars Hvam, Cipriano Forza

Published in: In the second round of review in journal, earlier version originally published in: Proceedings of World Conference on Mass Customization, Personalization, and Co-Creation, Montreal, Canada, 2015.

4.4.1.1 Research objective and research question

One of the main and first challenges in PCS projects from the planning to the maintenance phase is how to manage and handle the massive amount of knowledge needed in these types of projects. Knowledge Management (KM) in PCSs is one of the most time-consuming tasks for both domain expert and the configuration team. The increased complexity of products increases the number of products features to be modelled and maintained in the PCS (Ardissono et al., 2003). The configuration knowledge is often spread within the companies among various experts in different parts of the products (Hvam et al., 2008). Other valuable sources of knowledge are also available in internal software systems such as ERP systems, calculation systems and spread sheets documents (Friedrich et al., 2014). Therefore, early in the development phase of a configuration model, a knowledge acquisition and knowledge cleansing stage is required to centralize, model and formulate the product or process knowledge (Felfernig, Hotz, et al., 2014). In PCSs, the KM includes the lifecycle of knowledge from the time of acquisition (Tiihonen et al., 1996a) to modelling, validating, testing (Hansen et al., 2012), and finally updating and documenting phase (Haug, 2009). In fact, it is very important that the required knowledge for the PCS is available for the project team (Turley, 2007).

This study presents a framework, in which the KM process can scope the project knowledge and manage the large amounts of complex knowledge of PCS. The question to be answered will be:

> *What are the most important available steps related to KM in PCS projects, and how to formulate a framework for PCS projects.*

Based on the challenges in KM during PCSs, a literature study to find a KM framework for PCS projects performed, which reveals a gap in the literature. In the next phase, a detailed literature study was conducted to find KM frameworks for IT projects in general. The next step of the literature review aimed to identify tools and methods that have been proposed for the individual phases of the KM in PCS projects. Afterwards, the developed framework was tested and validated in an iterative process in one case study. This case study was used to improve the quality and usability of the proposed framework and rectify the drawbacks before testing it on multiple case studies.

4.4.1.2 Research contribution

The literature review shows the available frameworks for IT projects and at the same time reveals the differences between IT and PCS projects. Different authors discuss the different step/s but there is a significant lack of a framework to relate and sequence all the required steps. PCS relates to a great deal of knowledge that represents complexity relations among components or modules, such as configuration rules and assembly constraints (Jinsong et al., 2005). A number of frameworks are available in literature on KM for IT projects (Table 4-6). Different frameworks differ from 3 phases/actions to 6 phases/actions based on the level of abstraction. Even though these frameworks use different terms to address various actions/phases of the KM in IT projects, they present a number of similarities. There are several differences between an IT projects and PCS projects. The scope of PCS projects compared to other IT projects is one of them. The second difference is related to the details of each step for IT projects compared to PCS projects which makes us to develop a new framework for PCS projects.

Table 4-6 KM frameworks for IT projects.

Authors	Actions/phases included in KM framework
Basili and Weiss (1984)	1. Establish the goals of knowledge selection, 2. develop a list of questions of interest, 3. establish knowledge categories, 4. design and test knowledge collection form, 5. collect and validate gathered knowledge, 6. analyse the knowledge.
Kucza and Komi-Sirviö (2001)	1. Identify need for knowledge, 2. share existing knowledge, 3. create new knowledge, 4. collect and store knowledge, 5. update knowledge.
Komi-Sirvio et al. (2002)	1. Define scope and requirements for knowledge capturing, 2. acquire knowledge, 3. package knowledge.
Rodríguez et al. (2004)	1. Identify knowledge sources and resources, 2. identify kind of knowledge, 3. identify knowledge flows (graphical modelling techniques), 4. identify faults in the knowledge flow (analyse knowledge).
Reich et al. (2012)	1. Knowledge stock (relevant domain knowledge of the IT team, the business team and the governance team), 2. enable the environment (combination of the technological and social aspects of a project that facilitate knowledge practices), 3. knowledge practices (actions taken to map and share knowledge within and between the IT, business and governance teams in an IT-enabled business project).
Lech (2014)	1. Identification (determine knowledge sources and resources), 2. acquisition/creation, 3. transfer/dissemination, 4. storage/capture, 5. use/application.
McGinnis and Huang (2007)	1. Socialisation (scoping and deliverables), 2. Externalisation (formalise the knowledge to be explicit), 3. Combination (knowledge clarification and team communication), 4. Internalisation (new deliverables, improved documentation, improved training, and process refinements).

Framework development

As the PCS grows and gets more successful, the users' expectations increase as well as the requirements for the system (Barker et al., 1989); where further development and changes are of great importance for PCSs. That highlights the need of having an iterative framework for the KM as illustrated in Figure 4-11. In the first step the scope of the system is determined, secondly the knowledge acquisition is carried out, thirdly the knowledge is structured by use of special modelling techniques and validated and the last step is concerned with documentation and maintenance. The individual steps of the framework are illustrated in Figure 4-11 along with relations between the steps.

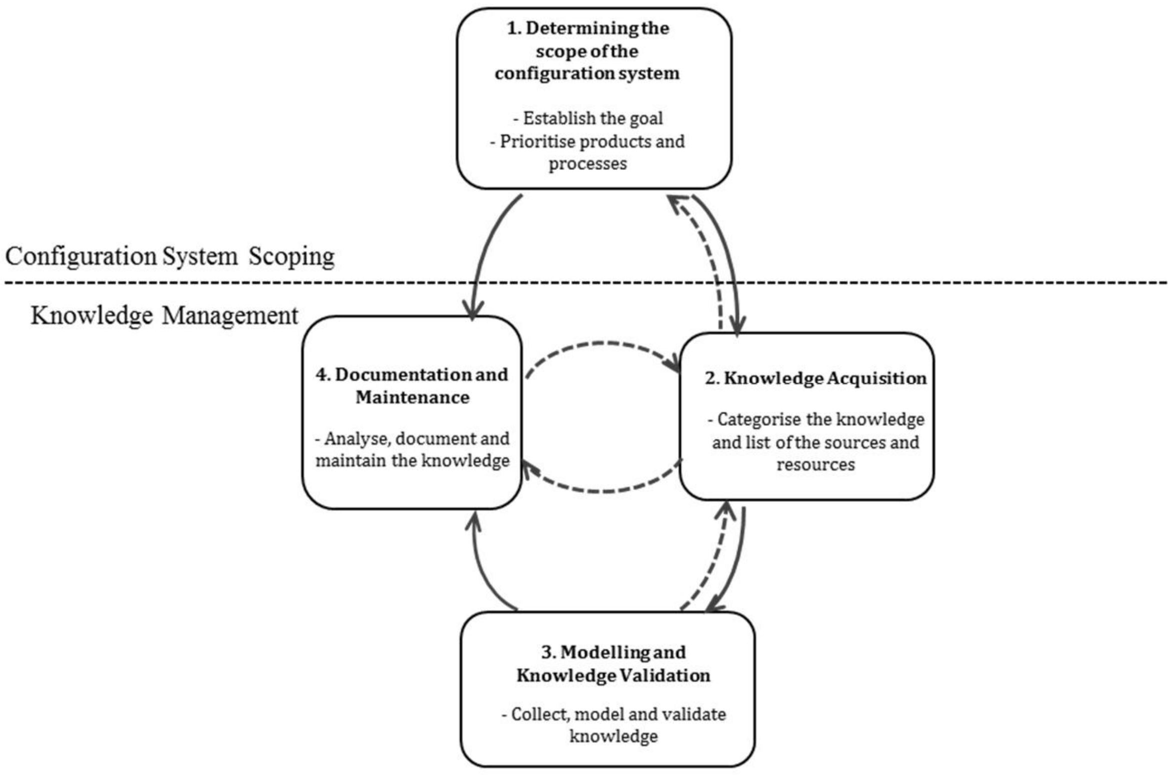

Figure 4-11 The proposed framework for knowledge collection in PCSs

Step 1: Scoping of the PCS

Project goals are determined by identifying stakeholders' functional and non-functional requirements. This step aims at increasing the understanding of the project by identifying the main stakeholders' requirements (Basili and Weiss, 1984). Based on the RUP methods, the stakeholders and their requirements can be drawn up by using process flowcharts (Compton and Jansen, 1990) and by utilizing the use case diagrams based on RUP methods (Kruchten, 2007) (Figure 4-12).

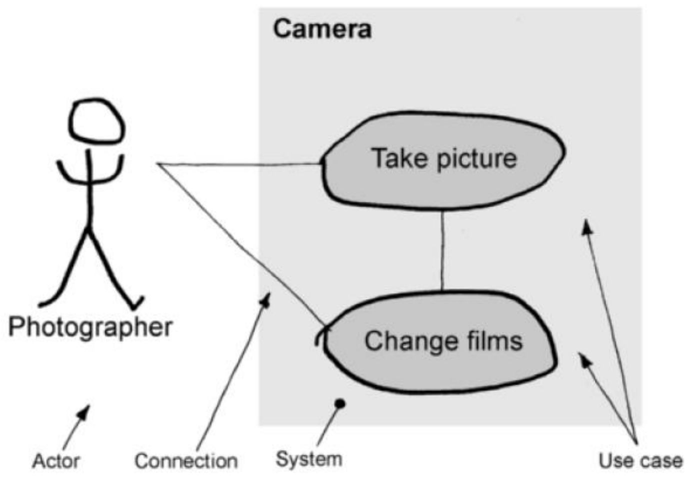

Figure 4-12. An example of a use case diagram (Hvam et al., 2008).

As discussed earlier in Paper A, for large and complicated project the component based approach is very helpful (Briand, 2003). Method recommended to be used in this step is weighting table, where each of the components is rated against several specific weighted project success criteria and a score is computed to rank the priority of the components (Wiegers, 1999).

Step 2: Knowledge acquisition

One method of knowledge clustering or categorization in PCSs is to determine the output knowledge according to the stakeholders' requirements and subcategorize them step by step. For example, regarding the outputs related to integrations, all the needed inputs and resources should be determined and categorized as integration category. Listing the sources and resources of the knowledge creates values in categorizing the knowledge and helps in delegating the tasks to different resources (Tiihonen et al., 1996a).

Step 3: Modelling and knowledge validation

There are variety modelling techniques which can be used for modelling, communication and further documentations in this step. Recommended modelling techniques are PVM and CRC cards.

Step 4: Documentation and maintenance of the knowledge

This step is of great importance as keeping the knowledge up-to-date is a key success factor in PCS projects. Modelling techniques are to be used as documentation tools beside the task of communication and validation. There are research works where the product modelling process is supporting by using software supports to integrate the different modelling techniques (PVM and CRC) (Haug and Hvam, 2007) (Shafiee, 2015).

4.4.1.3 Conclusion

Due to the differences between IT and PCSs, the available frameworks for KM in IT projects are not solving the KM challenges for PCSs. The proposed framework arrange the KM steps proposed in literature for PCSs by using available KM frameworks in literature for IT projects as a base. Therefore, based on literature, KM process for PCSs is divided into four steps (modelling and validation, knowledge acquisition, project scoping, documentation and maintenance).

The suggested framework has been tested in two industrial ETO companies on four PCSs projects in total. The configuration teams involved in the development and testing of the framework have expressed willingness to use the framework in future projects as it saved time and resources in the project. The cross case comparison showed that the framework behaved differently in company A and in company B. This could be traced back to the differences in the culture present in company A and Company B as previous studies illustrates results and job-oriented cultures have positive effects on employee intention in the KM process whereas a tightly controlled culture has negative effects (Chang and Lin, 2015). In order to validate the framework, Version 1 and Version 2 of the same project were compared in order to eliminate the threat of possible not-controlled influencing factors.

The ability of the framework to cope up with highly engineered, complex products in ETO companies indicates that it could also be used in PCSs, which involve less complexity. However, the necessity of applying such a structured framework in smaller projects is questionable and needs further testing. There are some limitations on framework regarding the suggested tools and techniques. The future works should specifically devote to find more efficient and simpler tools or techniques to be used in each steps of the framework.

4.5 Modelling and documentation

This section investigates the possibilities of assessments of the Section 3.7 that emphasized the importance of modelling and documentation in PCSs. Therefore, this section addresses the modelling and documentation of PCS in terms of visual knowledge management techniques and proposes an automatic solution for documenting the knowledge in PCS projects; which leads to better communication and validation of knowledge and system. This section aims to answer the RQ 4.

4.5.1 Paper H: The documentation of product configuration systems: A framework and an IT solution

Authors: Sara Shafiee, Lars Hvam, Anders Haug, Michael Dam, Katrin Kristjansdottir

Published in: International Journal of Advanced Engineering informatics, doi:10.1016/j.aei.2017.02.004, V.23, pp. 163–175. earlier version originally published in: Proceedings of 22nd Euroma conference, Neuchatel, Switzerland. Industrial version originally published in: IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT), Singapore.

4.5.1.1 Research objective and research question

PCS documentation includes modelling, maintaining and updating the product model, and storing all information related to the products' attributes, constraints and rules inside the PCS. PCS documentation requires the continuous involvement and communication of the domain experts. One of the main challenges of using PCSs is that the models can be poorly documented, incomplete, difficult to understand and outdated. For industrial companies, it is therefore crucial to have an efficient system for documenting the attributes and rules modelled inside PCSs to understand the consequences of changing the knowledge base and to enable discussions between PCS developers and domain experts.

This paper presents an approach (framework and IT documentation system) for an agile documentation process for the complete PCS lifecycle in order to validation of initial modelling, maintenance and further developments in the system. The aim is therefore to propose a structured documentation process which automatically generates the documentation as required for communication with domain experts. This process should ensure that no knowledge is duplicated and all the maintenance and updates are preserved in one place.

To support the framework, we develop an IT system that is capable of retrieving information available in the PCS and presenting it in a structure that corresponds to a product model, which can be used to document the system. The framework presents the knowledge and changes in the PCS (information model) and generates the documentation automatically based on the knowledge stored in the PCS. Aligned with the focus of the study, the following research questions have been developed:

> *How do we best frame the documentation framework for PCS projects using agile documentation methods?*

How can we develop an IT system to support the developed agile documentation framework of PCSs automatically?

To answer the research questions, in the first phase of the research, we studied the available literature on product modelling, documentation methods and agile documentation methods. For this study, the product (phenomenon) models, which are also used for documentation, are the Product Variant Master (PVM) and Class Responsibility Collaboration Card (CRC) cards (Hvam, et al., 2008). We chose the PVM and CRC cards methods because the research team and the case company are familiar with and have experience using both. After developing the framework, we examined the literature and investigated all methodologies and requirements for an IT documenting tool with a special focus on PCS projects. Figure 4-13 illustrates the complete process of developing the framework and the IT documentation system and explains the research steps and methods supporting different phases used. To evaluate the functionality, we tested the proposed framework and the documentation system. The testing aimed to discover (1) whether the structure, attributes and constraints could be extracted from a commercial PCS, (2) how to extract the knowledge from PCS and (3) whether the models made based on this solution were sufficient for domain experts and the configuration team at a company.

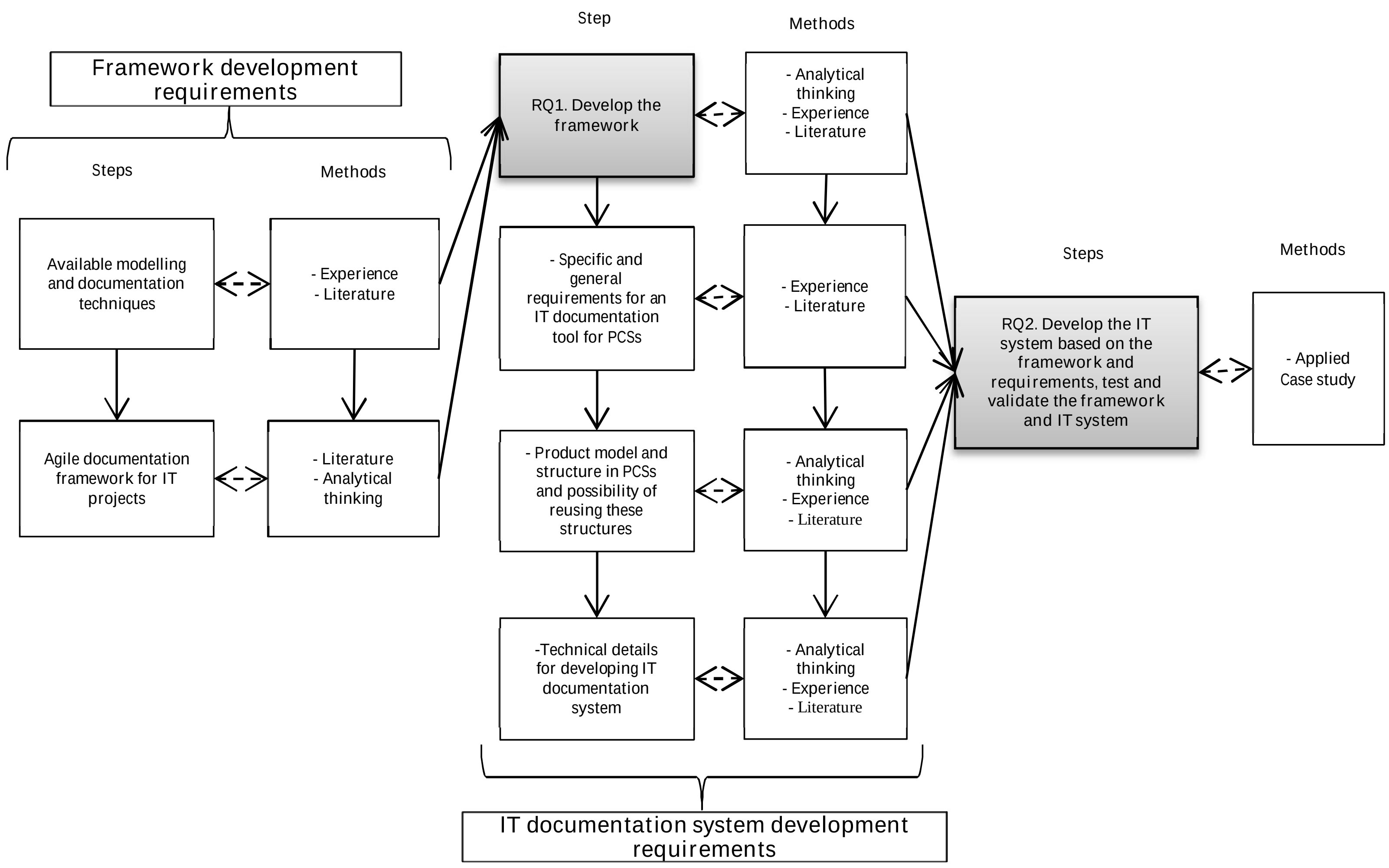

Figure 4-13 Methodology for developing the framework and the IT-based documentation system.

4.5.1.2 Research contribution

The literature review retrieve information needed to determine the methodology for developing the framework and the IT documentation system. The paper focuses on modelling and documentation in PCSs and the agile documentation principles for developing the framework. Then, the research is devoted to the requirements for developing an IT documentation system, the structure inside PCS to support the requirement for generating the documentation system and the technical details for generating this IT tool.

Framework development

This study presents a framework for agile documentation of PCSs, where the IT documentation of the product model supports the framework. The main idea of this framework is based on the approach of an agile lifecycle model (Ambler, 2002). The focus is to visualize the creation of a temporary model version and make it permanent when it is proved to be viable and trustworthy as a documentation system.

The framework demonstrates that, first, the initial product model should be built based on specific modelling techniques (in this study, we recommend using PVM and CRC cards). This phase is the temporary phase of documentation. Based on the initial modelling (PVM and CRC cards), the model is programmed into the PCS, and models similar to the PVM and CRC cards are generated from the PCS directly by the documentation system. For future versions of the PCS, updates will be made inside the PCS and the updated product models will be generated directly from the PCS without spending time on it. This permanent model will then be stored inside the PCS, and the maintenance and updating will be conducted in the PCS. Figure 4-14 demonstrates the processes for the agile documentation of the PCS.

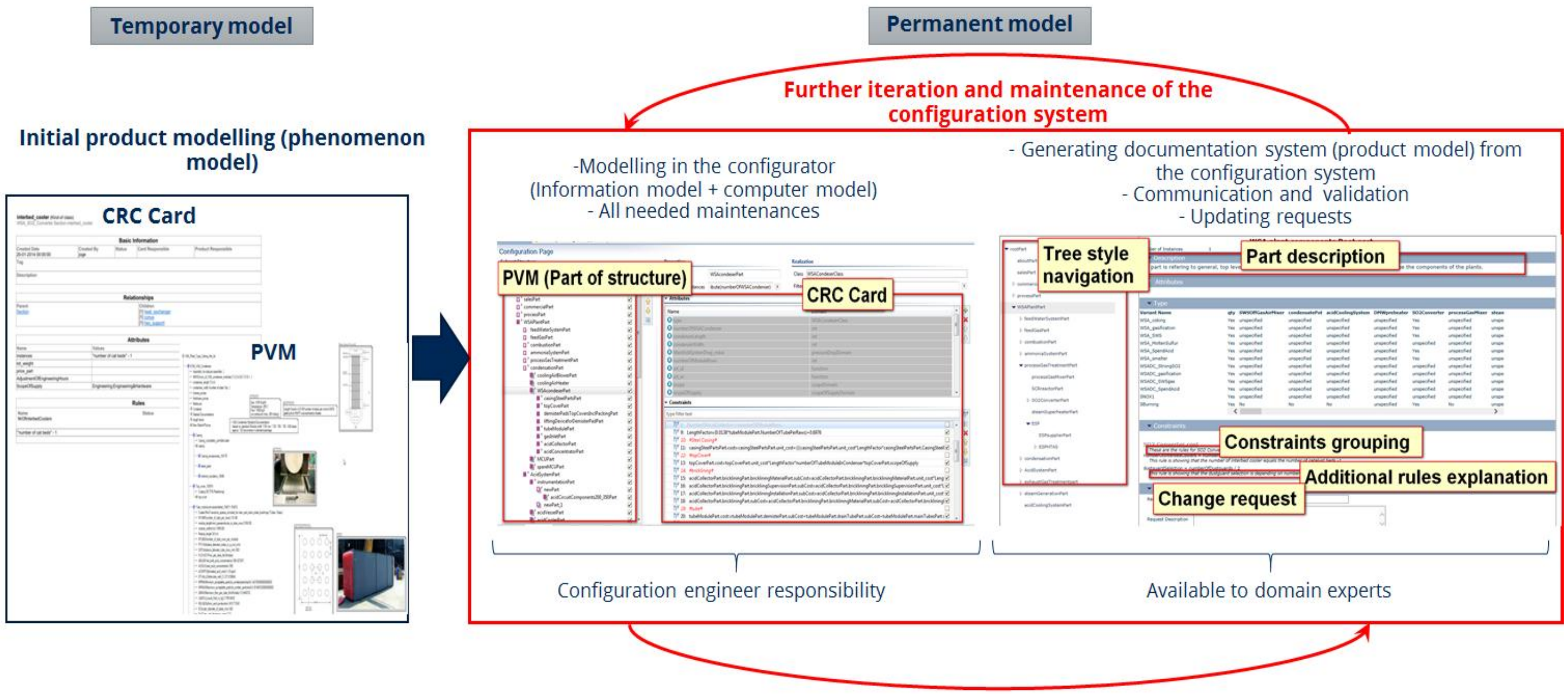

Figure 4-14 The process of generating documentation from the PCS (the photos will be shown in the case study).

The documentation model has been generated based on the structure inside the PCS and the configuration engineer only has to upload his PCS model to the documentation system. The programmers provide the team with the ability to control their models, such as show/hide different parts or providing users with descriptions. The model is shown as a tree structure inside the documentation system. The models that are uploaded to the documentation system are stored in the history as different versions. Domain experts can access the system depending on their rights managed by the administrator of the system.

They can see the tree structure and navigate between variants and constraints and ask for changes to any part of the model by sending a change request.

Development of the IT documentation system

Figure 4-15 shows a commercial PCS with structures that correspond to the PVM and CRC cards which was found by evaluating the main successful commercial PCSs on the market. All of the components and sub-components, including all of the attributes, constraints and rules, are listed in a tree structure. The goal is to transfer and translate all of the relevant knowledge into the documentation system and generate PVMs and CRC cards automatically.

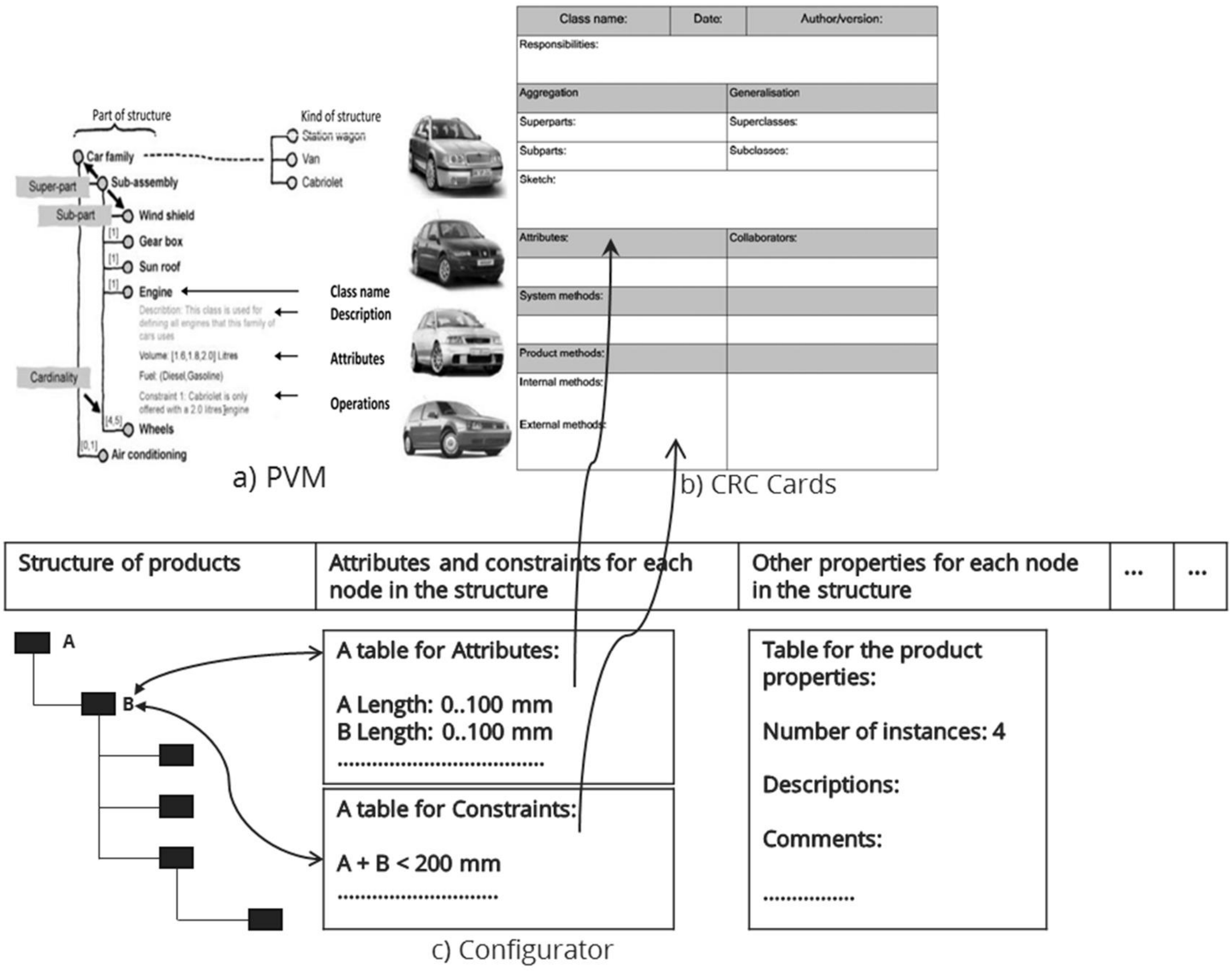

Figure 4-15 The relations between the product model and common structure in commercial PCSs. PVM and CRC Cards structure (a & b) (Mortensen, et al., 2008); traditional structure available in commercial PCSs (c).

The platform for the documentation system is a content management system (in this case Microsoft SharePoint). The original documentation format generated from a commercial PCS model (in this case Tacton) is based on xml format; by renaming the model file extension to .xml it can be read/ parsed. Figure 4-16 shows the interactions between SharePoint and the UI Renderer, which together are called the documentation system. For integration, we used the SharePoint JavaScript Object Model (JSOM). This JavaScript API is used for receiving lists and list-items from SharePoint and creating requests back in

SharePoint. The following is an example of how a request is registered to the request tracking list:

```
var clientContext = new SP.ClientContext('/sites/20');

var oList = clientContext.get_web().get_lists().getById('{7A6EFEDF-5D65-4241-A6E0-E84CF2F3312D}');
var itemCreateInfo = new SP.ListItemCreationInformation();
var oListItem = oList.addItem(itemCreateInfo);
oListItem.set_item('Title', $('#component_name').text());
oListItem.set_item('Body', $('#rfctext').text());
oListItem.set_item('Model', 'testtest2.dk');
oListItem.update();
clientContext.load(oListItem);
clientContext.executeQueryAsync(function() {
  alert('Item created');
  $('#rfctext').text('')
}, function(sender, args) {
  alert('Request failed. ' + args.get_message() + '\n' + args.get_stackTrace());
});
```

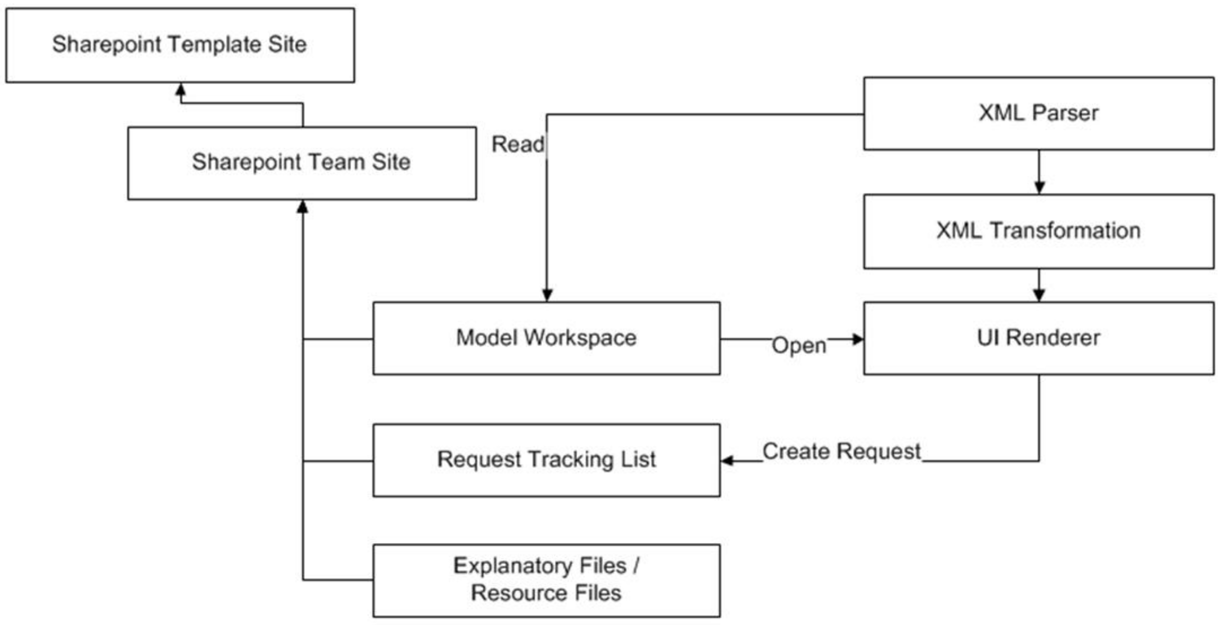

Figure 4-16 Interactions between the Content Management System and the UI Renderer (documentation system)

Case study

The proposed approach (framework and the IT documentation system) were tested on PCSs projects to assess the functionality. The company has five operational PCSs which support the sales and engineering processes to varying extents; it therefore enables us to test the documentation in different environments at the same company but with different levels of complexity. The system was tested during the development and operation of all five projects. The examples in all parts of the case are related to Project 2. Each workshop lasted between 30 minutes and 1 hour.

The initial phase involved product modelling to develop an increased understanding of the overall product, the individual components and the relation between these components using PVM and CRC cards. The PCS model contains all of the knowledge required for the documentation including the tree structure of the product and all the variants and rules.

Figure 4-17 illustrates the tree structure of the PVM and the CRC cards as generated by the documentation system based on the PCS model.

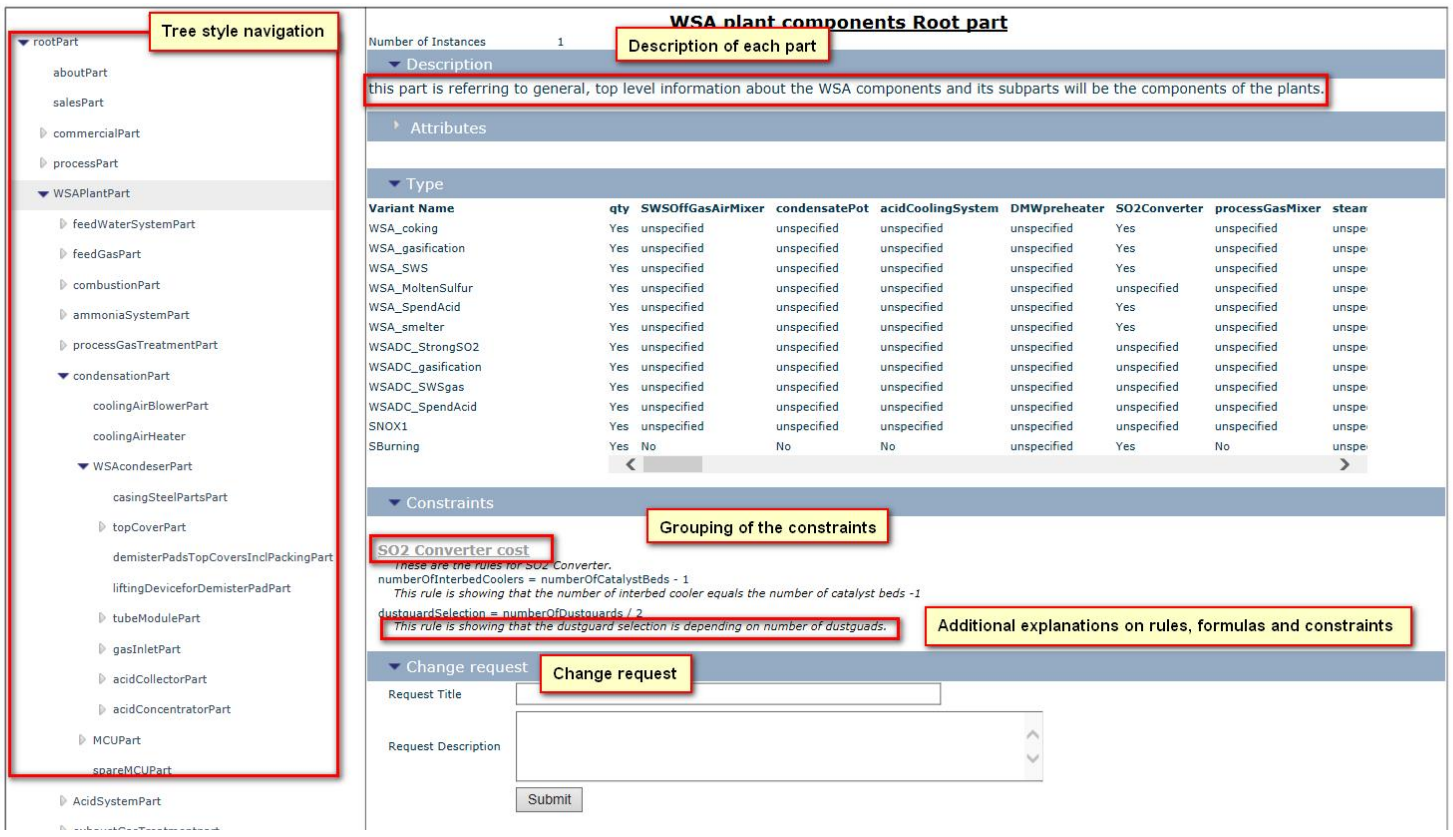

Figure 4-17 Knowledge generation in the PCS and PVM/CRC structure inside the IT documentation system.

4.5.1.3 Conclusion

We suggest a framework based on the agile model and previous literature, through which a temporary model can be created. Subsequently, the PVM and CRC cards are generated from the PCS, based on the structures, attributes and constraints within the PCS. This practical approach has been developed as an IT documentation system that supports the framework's principles. The proposed IT documentation system was implemented using the xml (standard) and JavaScript format at the case company.

Structured interviews, conducted in the testing phase to measure the usability of the new IT documentation system, indicated that the proposed method was useful in facilitating the understanding and debugging of the system. However, the approach might not be applicable to all kinds of commercial PCS (due to the differing structures of PCS). Various challenges might arise, depending on the mind-sets and cultures at different companies. We suggest, therefore, that future research should test the system using different projects, companies, types of software and platforms.

4.5.2 Paper I: Product configurators: A study of the impact of applying IT formal product modelling techniques.

Authors: Lars Hvam, Katrin Kristjansdottir, Sara Shafiee, Niels Henrik Mortensen,

Published in: In the second round of review in Journal, 2017.

4.5.2.1 Research objective and research question

This research opportunity is captured in this study; the impact of using a structured modelling technique, or the CPM procedure, is compared to less formal or none modelling techniques. The impact is analysed in terms of improved control of product variants, increased availability of the product knowledge in the organizations and employee satisfaction. The study is limited to experiences of using the CPM procedure and does therefore not study the quality of the CPM procedure relative to other suggested formal modelling techniques. The research focus is therefore on the experiences of using the CPM procedure relative to using less formal modelling techniques—i.e. structured bill of materials (Jiao et al. 2000; Hegge 1992) or non-formal modelling technique. Aligned with the focus of the research, the following propositions have been developed:

> *Proposition 1: The use of a formal modelling technique (CPM procedure) will result in improved control of product variants.*

> *Proposition 2: The use of a formal modelling technique (CPM procedure) will result in the increased availability of product knowledge in organizations.*

> *Proposition 3: The use of a formal modelling technique (CPM procedure) will result in increased employee satisfaction.*

4.5.2.2 Research contribution

The research reveals that in 18 companies, six companies used the CPM procedure, six use other modelling techniques (e.g. structured bill of materials) and the remaining six used non-formal modelling techniques. The research has illustrated that formal modelling techniques (CPM procedure) are used in the larger companies and in PCSs where the system include larger numbers of rules, attributes and integrations. Furthermore, three of the six respondents from the companies using the CPM procedure claimed that they started to use the more formal modelling techniques as the number of PCSs and the PCSs grew and involved more people. This indicates that in order for larger companies to be successful in managing a setup where there are several PCSs in operation with high complexity and numerous employees involved (often geographically dispersed), a formal modelling technique is required. The companies using the CPM procedure as a modelling technique claim to be more in control of their product knowledge and their product variants than the companies using less formal modelling techniques. This may be partly due to an increased ability to involve domain experts in the modelling process and thus ensuring that the right decisions are being made regarding which product variants to include in the PCSs. Furthermore, a more formal modelling technique makes it possible to keep track of the product variants, features and rules implemented in the PCS.

The impact of using the CPM procedure was measured in terms of a company's ability to document and share product knowledge, the ability to reduce the number of product variants in the company and the level of employee satisfaction among those involved in configurator projects. The respondents rated the impact on the categories according to the 5 point Likert scale from 1 to 5, where 1 means they strongly disagree with the statement and 5 means they strongly agree with the statement. In two cases a non-answer was provided, which was marked with NA. The results are listed in Table 4-7.

Table 4-7 Comparison of companies using the CPM procedure and less formal or no modelling techniques according to their ability to document product knowledge, control product variants, quality and employee satisfaction.

Company ID	Improved documentation of knowledge	Improved availability of product knowledge	Reduction of item numbers	Increased use of standard parts	Improved quality of products	Increased employee satisfaction
Companies using the CPM procedure						
Average	4.7	4.7	4.0	4.7	4.4	4.6
Companies using less formal modelling technique						
Average	4.3	4.5	2.5	4.3	4.2	3.8
Companies using non-formal modelling technique						
Average	3.7	3.8	2.2	4.0	3.8	3.3

The companies not using the CPM procedure seems to have less documentation and access to their product knowledge. However, the differences between the three groups in relation to documentation and the accessibility of product knowledge are not very significant. This could be related to the fact that the companies not using the CPM procedure have relatively small configurators, where they still can manage the complexity.

The reduction of product variants (item numbers) refers to the ability to eliminate unnecessary product variants from the product assortment. The ability to keep down the number of product variants is claimed to be an important enabler for reducing complexity and thus keeping down costs in the company (Hvam 2008; Lindemann, Maurer and Braun 2008). The companies using the CPM procedure claim to have a better ability to reduce the number of product variants than the other companies in the research, which may be related to an increased ability to document and gain access to product knowledge.

Finally, the companies that used the CPM procedure report that their employees are more satisfied with their working situation. This may be related to the increased ability to document and get access to product knowledge, which makes it easier for the employees to control the product knowledge implemented in the configurators and to communicate about the product knowledge with people from product development, sales and production, for example, and finally document all the knowledge using the CPM procedure.

4.5.2.3 Conclusion

The study has revealed an important correlation between the use of a formal modelling technique (in this case the CPM procedure) and the size and complexity of the PCSs as well as the ability to control the product knowledge and the products variants. However, these results raise further questions such as which specific features of the modelling techniques lead to an increased control of the product knowledge; and what is the correlation between the use of a formal modelling technique and the capability to successfully implement a PCS. It is also highly relevant to compare in more detail the impacts of using different formal modelling techniques. Finally, it would be beneficial to expand the number of companies included in the research.

4.6 PCSs in integration with other IT systems

This section investigates the possibilities of assessments of the Section 3.8 that refined the importance of integration of PCS projects with other IT systems. Therefore, this section addresses the integration of PCS systems with Internal and external IT systems across the supply chain; which leads to better knowledge management process and tasks automation in the organization. This section aims to answer the RQ 5.

4.6.1 Paper J: Automatic Identification of Similarities across Products to Improve the Configuration Process in ETO Companies.

Authors: Sara Shafiee, Lars Hvam, Katrin Kristjansdottir

Published in: International Journal of Industrial Engineering and Management, V. 8, No.3., earlier version originally published in: 17th International Configuration Workshop (pp. 139-145), Vienna, Austria.

4.6.1.1 Research objective and research question

It has been observed that in many firms the reuse and generalization of past experiences (often called "lessons learned") is becoming a key factor for the improvement, in time and in quality, of operational processes (Ruet and Geneste, 2002). Further, most ETO companies are using PCSs to simplify their specification processes (Hvam et al., 2008) when there is no framework available to connect the PCS with previous knowledge. Based on the literature, PCSs face a problem in ensuring the most satisfactory configurations for user requirements while observing the definition of the product family (Inakoshi et al., 2001). The idea is to make a connection between previous knowledge and the PCS when generating quotations in the PCS and compare it with the previously designed and sold projects from different perspectives. This means that if there is a high percentage of similarity between the current project and a previous project, the previous project can be reused, and thus the costs and resources required to meet the product specification will be significantly reduced (i.e. costs in the sales, engineering and production phases). This research therefore aims to answer the following research question (RQ):

> *How can we frame and create a clustering database for comparing the similarities from previously designed products in the configuration process?*

4.6.1.2 Research contribution

This previous research works in Section 3 are used as an inspiration for developing the framework, clustering the data for the comparison purpose, creating the database and integrating it with the PCS. There is no detailed discussion on how to make a database from the ERP system and how to cluster and constrain variants to access the old data. In this paper the aim is to suggest a framework in order to create a standard database for this comparison, where the currently available tools and methods can be utilized. Based on the literature, a four-steps framework has been developed, with the following individual steps:

1. Identify describing product variable within the PCS;
2. Retrieve specifications on previously designed products from the ERP system;
3. Identify a method to compare products based on describing variables; and
4. Set up the database with the previous products and integrate it with the PCS.

First, in order to guide the development and the implementation processes, clear objectives have to be defined. The next step is concerned with identifying application areas to support both the sales and engineering processes. In this step, the levels of detail and completeness that the PCSs has to fulfil are determined. There is often a trade-off between the level of detail and completeness, which is the number of components/modules included in the system. Sales PCSs often include a variety of products with a high level of detail, whereas technical PCSs have a greater level of detail but lower completeness as a result of being designed to support specific products.

Case study

The proposed framework was tested in an ETO company by finding the suitable clustering system, developing the comparison software and completing the integration of this software and the PCS. The team for this pilot project included four researchers from the university and two employees knowledgeable in ERP systems management. Figure 4-18 illustrates the process of delivering the comparison tool to the case company over four months.

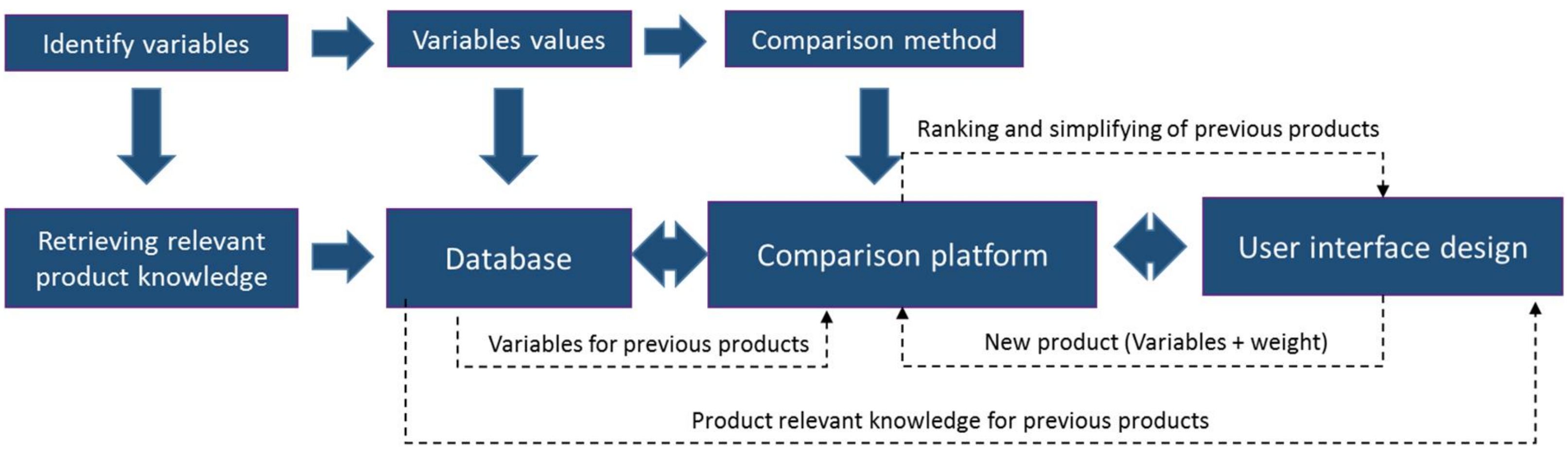

Figure 4-18 Structure and information flow of the comparison system in the case company

In the first step, the product features to be compared must be selected. Different methods such as PVM were used, and the desirable features were selected (Hvam et al., 2008). In the second step, all the variables and data were retrieved from the ERP system used at the company. Based on the main customized features determined in the previous step, one specific component with different variables was selected, and with help from the IT department it was possible to retrieve the cost documents from the ERP system into MS Excel spreadsheets. The first objective here is to select the best set of clustering variables leading to an optimized product grouping. Hence, the k-means procedure was run for every combination of the variables. Each one belonged to a different Excel sheet. In this case, there were four sheets for each cluster: x-y, x-z, y-z and x-y-z. In order to assess which, one would lead to the optimal clustering, the average Silhouette Index (SI) for all the analyses was stored. A higher SI means accurate clustering. The next step was the calculation of the distance between the new and old products based on the Euclidean distance. This was calculated for all combinations of the variables, that is, three variables (x, y, z) and six possibilities (xyz, xy, xz, yz, x, y, z). The idea is that a small distance between the new product and a previous product would indicate a high similarity. In Figure 5, the formula appears complicated, but the principle is simple based on Euclidean distance measurement. The IT system was developed based on the proposed framework and was tested in the case company with the available PCS and with the real products. The simple user interface is shown in Figure 4-19 after the Excel sheet is generated from the PCS. The Excel sheet is integrated with and receives all the inputs from the PCS.

Figure 4-19 Final user interface of the comparison system

4.6.1.3 Conclusion

In this research, we propose a framework for creating a database for the comparison of new projects against ones previously completed, which allows the comparison to be done in a standardized way while using the available methods and tools. Moreover, the proposed framework is tested in a case ETO company to determine whether the framework is practical in a real-life situation. The database was coded in a separated MS Excel as the pilot project using the minimum resources at the case company. The IT system showed the ability to cluster and compare the knowledge on the products and thus proved the concept. The system developed was integrated to PCS system to retrieve information from previous projects as an input to the proposal.

4.6.2 Paper K: Improved performance and quality of configurators by receiving real-time information from suppliers

Authors: Katrin Kristjansdottir, Sara Shafiee, Martin Bonev, Lars Hvam, Morten H. Bennic, Christian S. Andersen

Published in: Published in: 18th Configuration Workshop, Toulouse, France.

4.6.2.1 Research objective and research question

The recent advancement of cyber-physical systems has enabled a closer integration of supply chains relationships (Petnga and Austin, 2016), allowing for efficient ways of information management across multiple organizations. However, to make such an e-business environment possible, the established knowledge base needs to account for high degree of tailoring and dependency from suppliers (Klein, 2007). A technical approach that enables real-time information sharing across the supply chain by integrating PCSs has been proposed (Ardissono et al., 2003). However, the impact from receiving information directly from suppliers in the configuration processes has not been addressed in previous literature.

This paper aims to capture that research opportunity by analyzing: the overall impact from establishing the supplier integration, the gained benefits and the motivations for future investments, especially in ETO companies, and the challenges companies are faced within the process. Aligned with the focus of the research, the following propositions have been developed.

Propositions 1: By integrating PCSs across the supply chain, the complexity in terms of business rules, tables, parts and values, of the PCSs model can be reduced and consequently the modelling and development effort of the system will be reduced.

Propositions 2: By integrating PCSs across the supply chain, the quality of the product specifications in terms of increased accuracy – as the information included are optimized, more detailed and up-to-date.

Propositions 3: The more detailed specifications from the supplier make it possible to improve the overall designs, which lead to decreased cost both for the component in focus and for related Research contribution.

4.6.2.2 Research contribution

Based on the current literature in the field, the research highlights the importance of achieving greater integrations in the supply chain where IT plays a significant role. Furthermore, for companies providing customized products, there is a need for having up-to-date information across the supply chains. Therefore, by integrating PCSs across the supply chains, it allows companies to further integrate the flow of information and at the same time solve some of the main challenges concerned with MC and PCSs. However, the impact from increased integration across the supply chains by enabling interactions of PCSs across the supply chains has not been addressed in the literature. The data exchange between the case company and the supplier is done via .XML files. The case company sends 20 design parameters (such as min/max torque, the reduction in the gearbox, gear factors), which are defined in the previous steps of the configuration process. The request is to find a design within these parameters, where the supplier's PCS, based on their logic and business rules, find all possible design solutions, which can be around 100 and the prices for the designs. It is highly unlikely that the supplier PCS will not be able to find feasible solution. However, if that situation does come up either parameters have to be changed in the configuration at the case company or the supplier has to be contacted. The design solutions are sorted according to prices (from lowest to highest) and sent back on an .XML format via the web API web services. For this specific product, the prices are most important and therefore the cheapest solution is automatically selected by the case company's PCS.

Case study

The technical setup involves allowing the PCSs at both companies to interact (business-to-business communication) in order to retrieve real-time and accurate PCS from the supplier, which can be used in the overall configuration at the company. In Figure 4-20, the setup of the supplier integration is demonstrated.

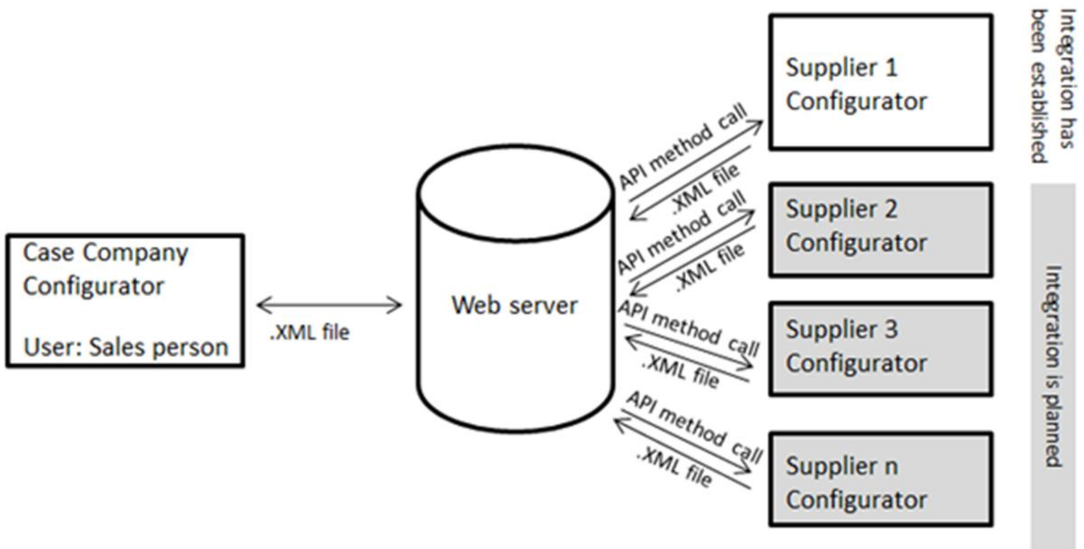

Figure 4-20 The technical setup at the case company: the supplier integration via API web services

This can be traced to improve the accuracy of the suppliers' data, optimal level of details, and up-to-date information which positively affects the cost of the overall design. With this setup the supplier does not have to revile the actual logic behind the designs and the pricing strategy as the supplier's configurator is treated as a black box in the configuration process. Furthermore, the complexity of the configuration models can be reduced and the time consuming task of modelling and maintenance are delegated to the supplier.

4.6.2.3 Conclusion

The present paper analyses the impact from having integrated PCS in the supply chain network in an ETO company. The approach suggests the involvement of PCS that retrieve accurate sub-product information in real-time from suppliers during the customization process. Three propositions were developed to analyse the impact from integrating PCS across the supply chains to retrieve more accurate and detailed information in the configuration processes

The modelling and development effort proved to be reduced at the case company as they are not responsible for modelling the supplier's product information. Thereby the modelling and maintenance effort is moved to the supplier. The findings support this propositions as the complexity, which is defined in numbers of business rules, tables, parts and values is reduced to almost zero. This also effects the development time of the system which is reduced from 8+ days to 2 and the specialist time spent on the development has been reduced from 8+ to zero. The quality of the configurators model in this article is defined in terms of improved accuracy as the information retrieved via the supplier integration are optimized, more detailed and up-to-date. The findings support this as over dimensioning of different parts is not required as a result to improve quality of the specifications. The result indicate that the company can save up to 20% of material cost as a result to immediate and in-direct savings gained from offer sizing of surrounding systems. The results based on this study indicate that significant benefits can be gained from increased supply chains integrations in ETO companies where integrated PCS are distributed across the supply chain.

4.7 Chapter summary

This chapter presents the results from the PhD project taken from different published articles based on different RQs and providing the validation of the contribution. The suggested methods and frameworks are developed based on the literature and experiences gained from working with PCS projects. The proposed solutions are tested in several case studies which are the evidence of the research project evaluation. As discussed, research is divided into five main RQs.

To begin with, chapter 4.2 is the answer to RQ.1 and the literature review and surveys helped in determining the benefits and challenges reported from academia and industry in order to clarify the RQs. In the first step, the framework for making strategies before starting the planning is suggested. Business cases are reported as one of the important phases of planning PCS projects and a framework for developing BCs is suggested and validated by testing in multiple case companies.

In chapter 4.3 where RQ.2 is answered, the scoping criteria and framework for PCS projects including all the needed future steps are proposed.

In RQ.3 and chapter 4.4, the challenge of KM is highlighted and the framework is proposed. The framework is tested and validated in multiple case companies while using the outputs from the previous phases in planning and scoping stages.

In RQ.4 and chapter 4.5, a framework, an automatic IT solution for modelling and documenting PCS projects is proposed. In another publication, a survey study evaluates the importance of using modelling techniques in industries.

The last RQ regarding different integrations aligned with PCS is answered by proposing IT solutions for doing the internal and external integrations (chapter 4.6). The first paper proposes a framework for clustering the similarities of previous and the new ordered projects throughout developing an Excel sheet and integrate it with PCS. The last paper discusses an IT solution to integrate the PCS inside the company with the venders' PCSs as an external IT system.

5 CONCLUSIONS

5.1 Contribution to theory

This section gathers the formulated RQs and the results of the research. Each RQ is answered by different papers and evaluated in different case companies. In this section, the answers to the main RQs are summarized including their sub questions developed throughout the thesis.

The overall research objective of this thesis is:

Research Objective: To frame and improve the management process of PCS projects: planning, development, and maintenance phases

In order to provide an answer to the objective, the research objective is divided into five RQs, which are answered below. The process of PCS projects within an organization can be performed taking into account the following areas:

- Structured business cases before planning the project, motivations, benefits and challenges in PCS management,
- Scoping PCS and having a structured planning phase,
- Managing knowledge in PCS,
- Modelling, documentation and maintenance of the PCS projects,
- PCS integration with other IT systems

Figure 5-1 illustrates different phases of PCS projects and PhD thesis contribution following Figure 2-1.

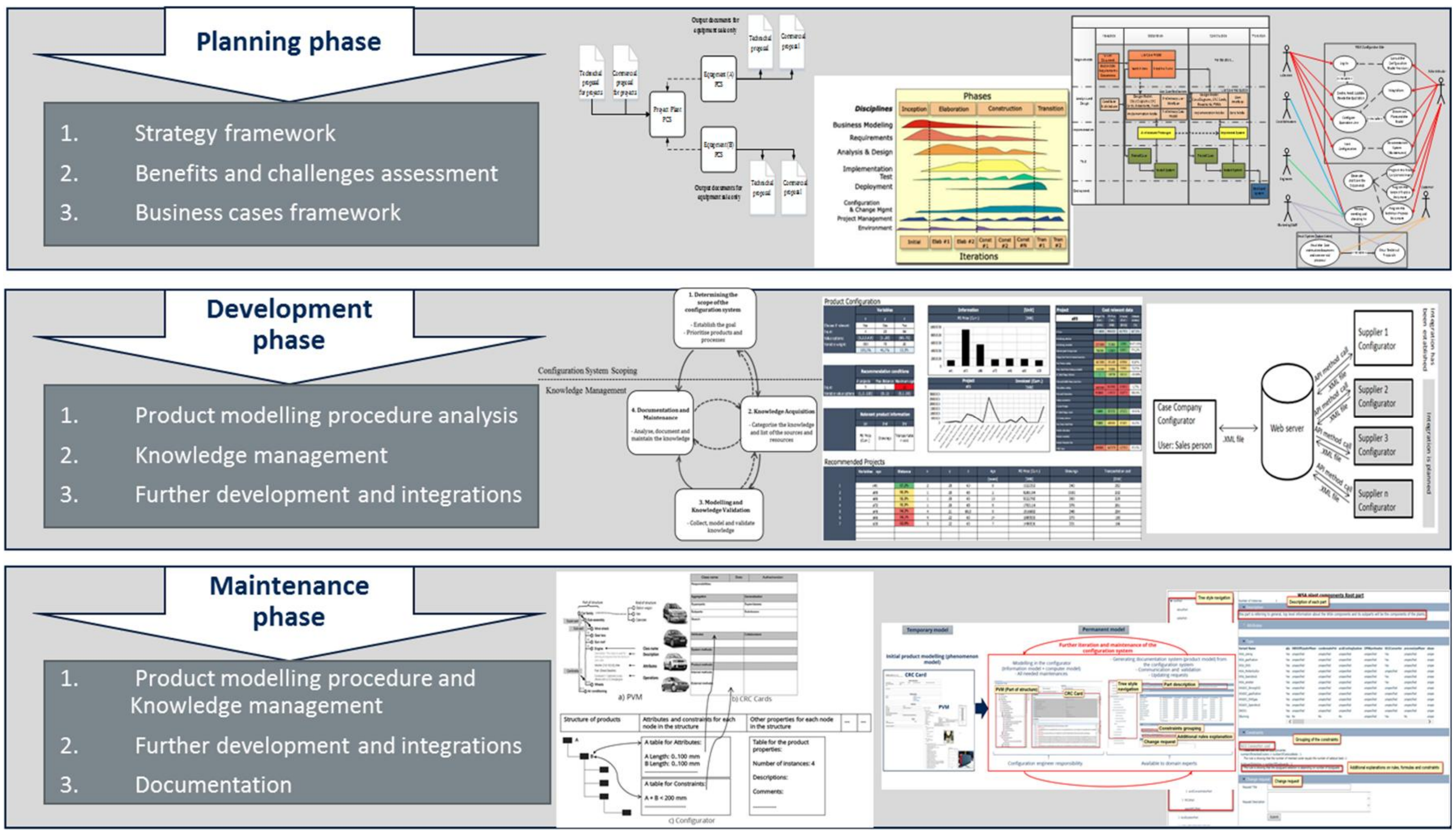

Figure 5-1 Individual phases of PCS projects and thesis contribution

Each of the main RQs (1, 2, 3, 4 and 5) focuses on mentioned five different aspects to be considered in PCS projects. The RQs and the answers are presented below.

RQ.1. How can PCS projects be planned?

RQ.1 refers to a standard management process to motivate the organizations for investing in PCS projects by considering the benefits and challenges. The answer to this question will be a BC framework for quantifying benefits, evaluating challenges, and considering critical parts and risks in PCS projects. This helps organizations to be aware of the challenges in the process while benefiting from PCS projects in order to prioritize projects.

RQ.1.1. How can we make a strategy to demonstrate different application of PCS projects?

The *RQ.1* can be broken down into two sub questions. To answer the *RQ.1.1,* a review on literature is conducted related to different applications of PCS projects. Moreover, a framework is suggested to facilitate the strategical decisions and it is tested in the case company (chapter 4.2). The main contribution of this answer can be summarized as follows:

1. Framework development for strategical decisions to demonstrate different applications and prioritizing PCS projects (Paper A): A framework is proposed with the aim to provide a structured approach to develop a strategy to guide the development and implementation processes of PCSs in ETO companies

2. Empirical case study validation (Paper A): The proposed strategy framework of PCS projects was tested in one ETO company. The results from testing the framework and observations of the case study facilitate the decision making process due to the analysis made in this step. The company was managed to solve the confusion challenge of selecting and prioritizing different projects and strategically used the outputs of previous projects to save time and resources in the IT architecture of their future PCS projects.

RQ.1.2. How can the benefits and challenges from different PCS projects be evaluated?

The answer to *RQ.1.2* includes a review of key publications and the investigation of relevant subjects from literature related to benefits and challenges in conducting PCS projects mainly in ETO companies (Chapter 3.4). Moreover, the established understanding was tested throughout the empirical investigation (Chapter 4.2). The main contribution of this answer can be summarized as follows:

1. In depth long-term quantification of cost savings from applying PCSs (Paper B): In this paper, we calculate the costs from PCSs and compare it to the cost of development, implementation and maintenance of the system. This study is conducted in a five-year period and in a single case company.

2. Survey analysis based on the application of PCS from motivations to realized benefits (Paper C): The motivations as a response to organizational needs are addressed and analysed based on a survey. The questions in the survey concerned what motivated these companies to invest on PCS projects. The result from the companies indicates how successful these companies are to achieve the benefits from applying PCS.

3. Survey analysis of challenges from implementing and using PCS based on survey and interviews (Paper D): This thesis established a detailed understanding of PCS challenges in organizations as a result of using PCS based on literature, interviews and surveys. The open questions were used to identify additional categories of challenges that are not described in the literature and to identify the specific challenges belonged to each of those categories. Then, the closed questions were asked to rate the importance of six categories of challenges identified in the literature on a five-point scale. The answers from companies helped to categorize the challenges which help the companies to be aware of possible investments in the future to avoid the challenges. These challenges could be listed as the possible risks in the BCs.

RQ.1.3. How can a standard business case for PCS projects be framed?

The answer to *RQ.1.3* includes a review of key publications and the investigation of relevant subjects from literature related to available BCs for IT projects and available steps for BCs in PCS (Chapter 3.4). Moreover, the established understanding was tested throughout the empirical investigation (Chapter 4.2). The main contribution of this answer can be summarized as follows:

1. Framework development for BCs in PCS projects (Paper E): Based on a literature review of key subjects, this thesis established a detailed understanding of general application of BCs in PCS projects (Chapter 3.4). Inspired by the available frameworks for IT projects, the available steps and tools in PCS projects' literature are listed (Chapter 3.1). Combining the literature with experiences leads to the framework development for BCs needed for PCS projects. The framework for making BCs for PCS projects was tested in multiple case studies (Chapter 4.2).

2. Empirical case studies validation (Paper E): The proposed framework for BCs of PCS projects was tested in two engineering companies. The results from testing the framework and observations of the case studies show the interest among the whole team in using the suggested BC framework as well as its challenges at the company.

RQ.2. How can PCS projects be scoped?

RQ.2 refers to a standard framework to scope PCS projects and make a success out of the investment. This framework makes the organizations aware of the decisions they have to make on the way and standardize the planning, development, implementation and documentation process based on RUP methods (Chapter 3.5). This question aims at reducing the needed time, resources and confusions during PCS projects. The main contribution of this answer can be summarized as follows:

1. Framework development for scoping the PCS projects (Paper F): In order to combine the literature review of available tools with experience, this thesis established a detailed framework and sequences of steps for scoping PCS projects. These steps evaluate the aims and benefits for the specific project, introduce tools for stakeholders' analysis as well as IT architecture and define the level of details. Moreover, it introduces the management planning from RUP to help in determining different phases of the projects.

2. Empirically validated significance (Paper F): The framework was validated in one case company and the detailed example of the tested project was provided to show the application of the framework. The testing results showed the impact of the framework on different phases of the project while reducing the needed time and resource.

RQ.3. How can we acquire and manage knowledge needed for PCS projects?

The answer to *RQ.3* requires a deep review of literature on the differences between general IT and PCS projects (Chapter 3.1). The literature review investigates the available literature on IT projects and PCS projects regarding KM. The investigations described KM frameworks on IT projects and the need of KM frameworks for PCS projects (Chapter 3.6). The research aims at reducing the efforts and cost for PCS projects by structuring the knowledge management process. The main contribution of this answer can be summarized as follows:

1. Framework development for knowledge management in PCS projects (Paper G): Aligned with a detailed literature review, this thesis established a structured framework and

sequences of steps for KM in PCS projects. This paper demonstrates different phases of PCS projects and how all these phases need documentation and management of the knowledge. The framework mentions the scoping needed to plan the project in a high level of abstraction before initiation. The scoping framework used in this phase was the results from *RQ.2* as the output of *Paper F*. After starting the PCS projects, the tools and method are introduced for knowledge acquisition, modelling and documentation phase. In knowledge acquisition phase, the importance of receiving right level of details for the knowledge in next steps is discussed. Modelling phase clarifies the impact of a clear communication regarding knowledge with the stakeholders; and the importance of knowledge validation on the quality of PCS projects. In the last phase, the knowledge maintenance and documentation for updates and further developments in PCS project are described.

2. Multiple case studies empirical evidences (Paper G): The framework was validated in two case companies on four different PCS projects. The research presents the analyses of the application of the framework and the cross case comparison in different companies' settings. The observations indicate that KM framework leads to improvements in the management process of PCS while reducing the needed time and effort for gathering and modelling knowledge.

RQ.4. How can the PCS projects be modelled and documented?

The answer to *RQ.4* requires a deep review of literature and understanding of different modelling techniques, communications tool, and documentation systems (Chapter 3.7). The literature review illustrates the need for formal modelling and documentation tools in order to save time and resources in the process of PCS projects. This question includes two sub questions, which will be summarized below. The answer to *RQ 4.1* outlines the results of the research on an agile framework for documenting PCS projects and IT tool development (Chapter 3.7). The second area of the research focuses on survey results about the application of formal modelling techniques and their benefits in PCS projects settings.

RQ.4.1. How can we automate the documentation, validation and communication process in PCS projects?

In *RQ.4.1,* the research aims at introducing a more efficient framework for documenting PCS projects, while it is supported with an IT tool to prove the application of the proposed framework. The outputs are listed as follows:

1. Framework development for modelling, documenting and communicating during PCs projects (Paper H): aligned with a detailed literature review, this thesis established a structured an agile framework for developing an automated documentation and modelling solution in PCS projects.

2. Developing an IT Tool (Paper H): Using the framework as the automatic solution and listing up the requirements for documenting IT and PCS projects from literature leads to an IT solution. The IT solution proved the application of the framework which indicated the satisfaction at the company based on the reviews.

3. Multiple case studies empirical evidence (Paper H): The framework is validated by developing the IT system and the IT system is validated by testing different PCS projects. The feedbacks form the stakeholders are gathered by interviews across the company. The usability of the system is proved which demonstrates the saving in time and resources in the case company aligned with a high quality in communication and validation of knowledge. The documentation is done in minimum amount of time using this automated documentation system. Meanwhile, the utilization is efficient and easy for the stakeholders.

RQ.4.2. How important is it to use the structured modelling and documentation techniques in PCS projects?

The *RQ.4.2* demonstrates the importance of documenting and modelling the knowledge from PCS projects in a structured way. The literature emphasizes on the importance of using formal modelling techniques for communication, validation and maintenance purposes (Chapter 3.7). This paper aims to show the real data from several companies illustrating the benefits of using modelling techniques on PCS projects development and performance (Chapter 4.5). The main contribution of this answer can be summarized as follow:

1. Survey and interview analysis based on the benefits of using modelling and documentation techniques: the research proved the correlation between the high degree of using visual modelling technique and high quality of development and communication. The results are based on answers from industrial manufacturing companies. The results indicate that companies using the formal modelling procedures tend to have an improved ability to reduce the number of product variants in the company, improved documentation of their product knowledge and higher employee satisfaction.

RQ.5. How can the integrations with other IT systems lead to improvements in the performance of PCSs?

RQ.5 verifies that PCS performance increase when it integrates with other IT systems (Chapter 3.8) and highlights the importance of achieving greater integrations in the supply chain where IT plays a significant role. The literature studies show the efficiency of PCS systems when they are aligned with other IT systems such as ERP systems, simulations and calculation systems, CAD systems and even external IT systems such as venders' PCs systems. The main contribution of this answer can be summarized as follows:

1. Framework development for analysing the similarities between configured products (Paper J): Literature introduces a framework for comparing the previous sold products and the new configured orders through PCS. This research suggests a framework where

product features from the company's PCS are clustered in order to compare with previously made products by retrieving information from the proposed database. This framework and the proposed database are tested in one case company.

2. IT tool development and case study validation (Paper J): The IT tool developed to support the suggested framework and aimed at clustering and assessing the similarities for a specific product at the case company. The IT tool is a proof of concept and demonstrates the possibility for these kinds of automations in industries based on configured products from PCS projects. The case company satisfaction from this IT tool verifies the potential of analysing the similarities among projects for other product and in an automated way.

3. In-depth analysis of integrating the PCS across the supply chain to receive real time information from suppliers (Paper K): The result presented in this study are reported from an ETO case company used the proposed framework and solution for a period and measured the benefits which can be achieved by integrating PCSs across the supply chains. The benefits reported from the case study are quantifying based on the saved man hours for receiving the knowledge from different venders and qualifying based on the short response time and error free documents sent to the customers.

4. IT tool development and case study validation (Paper K): The It tool is developed based on the framework by using .XML format via the web API web services. The results from using this automated solution shows a lot of benefits at the case company listed as: complexity reduction, quality of the specification process, and cost savings.

5.2 Contribution to Practice

Drawing on the answers to the RQs, this section discusses the practical significance of this PhD study in Table 5-1.

This PhD study focuses on the case company Haldor Topsoe A/S for stablishing, developing, and maintaining PCS projects. The observed challenges in practice is based on real experiences working with PCS projects in real organizational settings. Combining the real experiences and challenges with academic results leads to contribution to theory and practice.

Table 5-1 PhD study's contribution to practice and theoretical challenges

Practical Challenges	Theoretical Challenges	Contribution of the PhD
RQ1. How to identify the possible long-term and short-term benefits from PCS project? How to have a wise selection and prioritization of PCS projects? How to make a business case for PCs projects?	There are research works on general benefits of PCS projects. The researchers try to show benefits or introduce tools and methods on how to select and prioritize the PCS projects in industries to get the most benefits out of them (Chapter 1.2). However, there is no framework to develop BCs and guide identification of the future projects which are cost and time beneficial (Chapter 3.4). There is a need for surveys, interviews and in depth studies in order to prove the success and benefits of PCS project. There is further need for a framework and template for BCs in Pcs projects.	First of all, by literature reviews and experiences from different project, a framework for prioritizing and making strategic planning for PCS projects is developed. The results were a strategic plan reported to the case company for the future projects (Chapter 4.2). Secondly, illustrating the results and success rates in PCS projects from other industries is one of the main motivations to invest and use PCS projects. The awareness of the challenges for all the companies leads to better planning and risk assessment. Furthermore, the challenges reported from surveys warn all the industries about the bottlenecks on the way (Chapter 4.2). By reviewing all the available literature for IT projects in general and PCS projects specifically (Chapter 3.1), we found trends for framework and we added the available tools to the frameworks. The results lead to a BCs framework which makes the selection, planning and prioritization efficient at the case companies (Chapter 4.2).
RQ2. How to scope and manage PCS?	There is available literature on different steps of managing and planning different phases of PCS projects (Chapter 3.5). There is no framework to guide the practitioners step by	By reviewing the available steps for planning, implementing, developing, and maintaining PCS projects, this study suggests a framework for scoping PCS project from planning to documentation phase (Chapter 4.3).

Practical Challenges	Theoretical Challenges	Contribution of the PhD
	step through different stages of planning, implementation, development, and maintenance. A framework is required to contain available tools and methods to introduce a simple efficient process for planning, implementation, developing, and maintaining PCS projects	In this framework, the stakeholders' requirements are analysed in the first step which is reported as a challenge in PCS projects. We aim at analysing the current process of tasks and proposing the future process, benefiting from the available tools. Determining the IT structure and number of needed IT developments is one of the confusions for all practitioners. This framework proposed the methods to prioritize different components in one specific PCS project. The study aims to clarify how to plan the project iteratively as well as how to manage the maintenance and documentation of the system in the future. Most of the inputs for this phase is based on the outputs from BCs in the previous RQ.
RQ.3. How to have an efficient framework for acquiring the complicated knowledge for PCS project?	Previous studies address how complicated is to gather and group the needed knowledge for PCS projects. Some studies suggest tools and methods to simplify the KM process in PCS projects (Chapter 3.6). Other studies just report the challenges regarding KM and complexities about knowledge for PCS projects. There is no framework to scope and standardize the steps in KM process in a sequential manner. Having a standard framework for gathering and prioritizing knowledge in PCS project will lead to saved time and resources both from business and PCS team.	This study clarifies the concept of KM in IT project and the available proposed frameworks for IT projects (Chapter 3.1, 3.6). The conclusion of literature study is a framework inspired by KM framework for IT projects and available steps for PCS. The framework facilitates the managing of the knowledge from the planning to the maintenance phase of PCS projects (Chapter 4.4). The application of the framework in different companies and projects demonstrates the satisfaction rate from practitioners due to an efficient KM procedure in PCS project. The Scoping of the PCS projects and the outputs from previous RQ is needed for KM process in this stage.
RQ.4. Howe to model the product, document and validate	Further developments and maintenance of product knowledge explains the attention of the literature to the modelling and	The study suggests an agile framework for automatic documentation and modelling of PCS projects. The framework is designed in a way to skip any over-writing and duplication of

Practical Challenges	Theoretical Challenges	Contribution of the PhD
the knowledge in PCS projects?	communication techniques (Chapter 3.7). The PCS project should be updated based on the products changes at the company. The product knowledge has to be communicated and validated all the time. Therefore, the companies need an efficient way of modelling and documenting the knowledge. There is a need for research on how to do documentation in the most efficient way but there is a need for an IT tool to automate the whole documentation process without a need for redundant work and resources.	knowledge in order to have an agile knowledge documentation (Chapter 4.5). The framework results in an IT documentation system which automate the whole process of modelling, communication, validation and documentation of the knowledge inside PCS. The results from the usability of the IT documentation system demonstrates the satisfaction and improvements as well as cost savings in the development, testing and maintenance process. The documentation and maintenance plus communication and validation of knowledge are two important phases of the RQ.3.
RQ.5 How to get the most benefits out of PCS projects by integrating them to other IT systems?	The literature refers to the efficiency of PCs project while integrating with other IT system such as ERP or CAD systems (Chapter 3.8). There are researchers focusing on IT aspects of development while efficient management of connecting these IT systems is underestimate. This study presents frameworks in order to simplify the integration of IT system with PCS projects, without any focus on IT technical challenges.	The study reviews the available literature of possible integrations with IT systems in order to retrieve the old knowledge of products. This will lead to a framework for clustering the products to assess the similarities of the old products and the configured products (Chapter 4.6). An IT tool is developed to support the framework and the results from using it in the case company show saved man-hours because of the automations. The relations in supply chain and venders' management is one of the main challenges in order to receive the real time response and costs for the customers. The research took this opportunity to propose a structured way align with the IT solution suggestions, which will help the company to integrate their own PCS with the ones from customers. This will help the company even to compare different suppliers in terms of quality, price and etc. and select the most beneficial vender in terms of their customers' preference (Chapter 4.6).

5.3 Research limitations

The underlying methodological implications of this research should be acknowledged as presented below:

Generalizability of the research: This research was undertaken as an applied research project within the Operations Management research group with the collaboration of Haldor Topsoe A/S. Different factors limited the generalizability of the studies in this thesis including: stakeholders' requirements in different industrial settings, product and projects types, and finally industry types used as case studies in the research work. Otherwise, Haldor Topsoe A/S and other case companies used in this study are well known as ETO companies producing highly engineered complex products and process plants. The case studies types allow the research group to face the most complicated types of PCS projects and repeat the in-depth long-term testing of the developed methods and tools. Meanwhile, the study of one case company gives the team the opportunity to have hands in practice directly and IT developments to assess the research in real work in a long-term period. Furthermore, more ETO case companies make the results general for ETO companies.

5.4 Opportunities for future studies

This PhD project resulted in several frameworks and methods which could arise opportunities for the future research.

1. Referring to the all RQs, in order to motivate and assess the PCS benefits from 1) planning, 2) scoping, 3) KM process, 4) documentation and modelling, 5) effective integration with other IT systems, several frameworks and methodical instruction (theory contribution) are introduced. These suggested frameworks and tools are tested in limited numbers of ETO case companies. ETO companies represent complicated highly engineered products and services which could cover other less complex products. Further testing could generalize the suggested approaches or improve them to be stable in all industrial settings and for all kinds of PCS projects. This research is an in-depth case study report in order to evaluate the challenges in industries and contribute to the theory and practice. The further research could focus to implement and test all reported challenges and solutions in a wide range of stakeholders and types of industries.

2. The second opportunity for future studies is the steps of the framework which have received less attention from academia and reported as a big challenge in practice. One of these challenges is the organization influence on user acceptance or rejection of PCS projects. The organizational challenges such as change management is reported as one of the main risks of the PCS projects based on literature and this PhD study.

3. The other well-known aspect of the organizational challenges is the risk management. Assessing the risks of PCS projects and their influence in PCS projects failure and finding the proper solutions could be beneficial both for the industry and academia. Elaborating on risk management in PCS projects could be beneficial both in BC and planning phase and in implementation phase.

4. The third research opportunity is the integration between PCS and other IT systems in industries such as simulation tools, CAD systems or ERP systems. Benefits could be achieved if PCS could communicate with other IT systems. More specifically, Integration with the ERP system to receive customer information, create 2D and 3D figures in the CAD system based on the configured knowledge, or simulate complicated calculations in the simulations and calculation systems. Some questions regarding integrations are answered in this PhD thesis and the available literature, while there are still many unanswered questions about the possibilities and solutions for potential integrations. There are great interests and potentials in industries for new frameworks and IT solution for integration purposes.

5. One of the important phases of PCS projects, which are not discussed in this thesis due to the time restrictions, is the implementation phase. This phase is very interesting both for academia and industries and have not yet attracted a lot of attention from academia. This phase contains the managerial proficiency to launch the system, test and validate the system and enforce the users to replace it with their current ways of working.

5.5 Concluding remarks

In Conclusion, the frameworks, methods and IT solutions tested in the case companies indicate the efficacy in planning, developing, documenting and maintenance of the PCS projects. In general, the time and resources needed for each of the phases are reduced due to the proposed solutions. These solutions including the frameworks and IT automations lead to cost savings as well as qualitative benefits. Therefore, in order to answer the main objective of the thesis from both the theoretical and practical perspectives the main contribution can be listed as:

1. Literature reviews and survey investigations: The literature knowledge helps the researcher to find the gaps and challenges in the industry. The surveys conducted during the thesis improve the understanding of the industries opinion on benefits, challenges and the impact of the formal modelling techniques on their daily work. The surveys illustrate the influences of academic results as well as gaps in the literature and also provides industries with knowledge from other industries. Both literature and surveys were the foundation for the PhD project while the importance of the experiences of working with PCS projects in practice cannot be underestimated.

2. Frameworks development: Developing different frameworks is the result of reported challenges in different phases of PCS projects. These frameworks aim at standardizing and formulizing different phases of PCS projects in order to have an efficient project management and saved man-hours. The developed frameworks include tools and methods aligned with IT solutions.

3. IT tools support: The IT tools are developed to support the frameworks and prove the application of the framework. The value of the IT tool for industries is the automation of the working processes while providing an easy efficient solution. These IT tools are tested in case studies to assess the satisfaction rate among users compared to the old routine solutions.

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7 APPENDED PAPERS

ARTICLE A

ARTICLE B

ARTICLE C

ARTICLE D

ARTICLE E

ARTICLE F

ARTICLE G

ARTICLE H

ARTICLE I

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ARTICLE K